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THE PM_{10} SAMPLER EVALUATION PROGRAM: JANUARY 1985 TO JULY 1986

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16. ABSTRACT

This report summarizes the activities conducted at the Environmental Monitoring Systems Laboratory's wind tunnel test facility in RTP, NC from January 1985 to July 1986. During this period, the wind tunnel test procedures proposed for PM_{10} reference and equivalent methods (49 FR 10454) were evaluated and revised. Several shortcomings in the particle sampling and analysis procedures used in the wind tunnel test facility were identified and eliminated. Specifically, the aerosol distribution system was redesigned, the differences in concentration measurements between an isokinetic high-volume sampler and an array of isokinetic sampling nozzles were investigated, the repeatability of replicate isokinetic sampler measurements was determined, the precision of the analytical technique (fluorometry) was determined, and velocity and turbulence profiles were measured over the range of wind speeds used for testing. The Andersen Samplers Model 321A and the Wedding IP_{10} high-volume size selective inlets (SSI) were evaluated in the wind tunnel over a range of particle sizes (3-20 micrometers nominal aerodynamic diameter) using both liquid and solid test particles at two wind speeds (2 and 8 km/hr). In addition, two Wedding IP_{10} SSI's used in an EPA field study in Phoenix, AZ in early 1986 were also tested concurrently with a unexposed (clean) reference Wedding IP_{10} SSI.

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ABSTRACT

Test inlets designed to measure the atmospheric concentration of particulate matter smaller than a nominal 10-micrometer (μm) aerodynamic diameter (PM_{10}) were tested at the EPA wind tunnel test facility in Research Triangle Park, North Carolina. The Andersen Samplers Model 321A and the Wedding IP_{10} Size Selective Inlets (SSI's) were evaluated following the procedures proposed in 40 CFR Part 53 (Ambient Air Monitoring Reference and Equivalent Methods). The tests consisted of measuring the inlet effectiveness over a range of particle sizes (3 to 20 μm nominal aerodynamic diameter) using both liquid and solid test particles at two windspeeds (2 and 8 km/h). Additionally, two field-tested Wedding IP_{10} SSI's (EPA field study at Phoenix, Arizona, May 1986) were compared with a clean "reference" Wedding IP_{10} SSI.

Before conducting the above inlet tests, the requirements of 40 CFR Part 53 were revised to make the inlet tests more practical, and several shortcomings in the sampling and analysis procedures as previously practiced were eliminated to ensure compliance with requirements in 40 CFR Part 53.

The Andersen Samplers Model 321A and the Wedding IP SSI's both were found to meet the 50-percent cutpoint requirement (10 ± 1 μm) at 2 and 8 km/h for both liquid and solid aerosol particles. The field-tested Wedding SSI's did not meet the 50-percent cutpoint criterion. However, all samplers met the expected mass ratio requirement of ±10 percent of the mass predicted for an ideal sampler. Both the sampling effectiveness values for the ideal sampler and the aerosol size distribution used to calculate expected mass appear in 40 CFR Part 53.

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SECTION 1

INTRODUCTION

On March 20, 1984, the U.S. Environmental Protection Agency (EPA) proposed revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter. New primary standards were proposed for particulate matter measured as PM_{10} (particles with aerodynamic equivalent diameters less than a nominal 10 micrometers [μm]). A new Federal Reference Method (FRM) for the determination of PM_{10} in the atmosphere and provisions for the designation of reference and equivalent methods for PM_{10} determination also were proposed. Under the provisions of these proposed regulations, candidate reference and equivalent methods for PM_{10} determination would have to be tested in accordance with explicit procedures contained in 40 CFR Part 53 (Ambient Air Monitoring Reference and Equivalent Methods). Following satisfactory completion of all test requirements, candidate methods would be formally designated as reference or equivalent methods. The proposed testing requirements of Part 53 include wind tunnel tests for sampling effectiveness and a 50-percent cut-point.

Concurrent with the development of the PM_{10} FRM and sampler performance requirements, EPA developed the in-house capability to test candidate PM_{10} samplers independently and to evaluate the proposed test procedures and performance specifications. A closed-loop wind tunnel test facility with a 122 cm x 152 cm (4 ft x 5 ft*) test section has been fabricated and put into operation at EPA's Environmental Monitoring Systems Laboratory (EMSL) in Research Triangle Park, North Carolina. Testing of candidate PM_{10} samplers was initiated in June 1984. During the period from June 1984 to January 1985, tests were conducted on an Andersen Samplers Model 321 Size Selective Inlet (SSI), an Andersen Samplers Model 321A SSI, a converted Andersen Samplers

*A metric conversion table has been made available as Appendix B for units used in this report.

Model 7000 SSI, a Sierra-Andersen 10-μm Dichotomous Inlet, a Wedding GMW PM_{10} SSI, a Wedding IP_{10} SSI, a Wedding IP_{10} Dichotomous Inlet, and several field-tested Wedding IP_{10} SSI's. All tests were conducted at a single windspeed (8 km/h) using liquid aerosol particles covering the size range from 5 to 20 μm nominal aerodynamic diameter. Solid particle tests (glass beads and/or ammonium fluorescein) were conducted only at a particle size of 20 μm and a windspeed of 8 km/h.

Several shortcomings in the sampling and analysis procedures became apparent following this initial test series. Subsequently, the procedures were revised and upgraded. The areas that received the most attention were (1) concentration uniformity in the wind tunnel at all combinations of windspeed and particle size, (2) differences between the concentration measurements obtained with an isokinetic rake (an array of sampling nozzles) and high-volume isokinetic sampler, (3) repeatability of duplicate isokinetic sampler measurements, (4) precision of the fluorometer covering the various instrument ranges used during normal operation, (5) reproducibility of velocity and turbulence intensity profiles, and (6) upgrading of equipment used in support of the wind tunnel operation.

Revisions to the wind tunnel test procedures were completed in January 1986. Testing of candidate PM_{10} inlets then was resumed. The first test was conducted on the Wedding IP_{10} SSI and was a preliminary study designed primarily to check out the new procedural and operational changes. The inlet was tested with both solid and liquid particles at a windspeed of 8 km/h. Following this preliminary test, sequential tests were performed on the Wedding IP_{10} SSI and Andersen Model 321A SSI using both solid and liquid particles at windspeeds of 2 and 8 km/h. A field-tested Wedding IP_{10} SSI then was run sequentially with the "clean" Wedding IP_{10} SSI used in the previous wind tunnel tests. A Wedding inlet that was cleaned during the field study then was tested sequentially with the "clean" Wedding reference inlet.

This report focuses on work performed at the wind tunnel test facility from January 1985 to July 1986 and is organized in the following manner. Section 2 contains the conclusions drawn from the work performed and recommendations for future work. Section 3 contains information about physical changes made to both the wind tunnel and aerosol distribution system, characterization

of the wind tunnel aerodynamics, determinations of the precision of the analytical technique (fluorometry), and descriptions of new equipment purchased in support of the wind tunnel operation. Each subsection begins with a brief description of the significance of the given topic (pertinent requirements of the proposed 40 CFR Part 53 test procedures) followed by an explanation of the steps taken to improve, correct, or otherwise modify a given procedure. Section 4 contains interim reports prepared at the completion of each inlet test. The reports in Section 4 begin with the first test conducted after all the changes outlined in Section 3 were completed.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Guidelines for performing wind tunnel tests on candidate PM_{10} inlets appear in 40 CFR Part 53. Among other criteria, these guidelines specify the maximum allowable deviation in aerosol concentration in close proximity to the test sampler, the maximum allowable relative error in the analytical technique, and limits on the quality of the velocity profile in the wind tunnel. The changes made to the test protocol at the EPA wind tunnel test facility have made it possible to meet all requirements set forth in 40 CFR Part 53 regarding wind tunnel tests.

The Wedding IP_{10} and Andersen Samplers Model 321A SSI's both met the requirements for 50-percent cutpoint at windspeeds of 2 and 8 km/h using both liquid and solid particles. All the inlets tested in the wind tunnel, including the field-tested Wedding IP_{10} SSI's, met the expected mass ratio requirement.

Further tests need to be conducted on both the Wedding IP_{10} and Andersen Samplers Model 321A SSI's returned from the Phoenix III field test (May 1986). The inlets' performance in the wind tunnel then should be compared with the relative performance found in the field test.

Tests still must be conducted at 24 km/h with both solid and liquid particles to complete the series of windspeeds required in 40 CFR Part 53. The new rake flow system currently being installed should be completed before tests are run at 24 km/h to ensure adequate quantities of uranine are collected for fluorescence measurements.

The sampling effectiveness curves generated for the test inlets have not been corrected for the presence of multiplets. Multiplets occur when two or three particles aggregate, forming a single larger particle. At present, no single algorithm for the correction of multiplets has been accepted widely. A single correction method should be developed and applied consistently to all sampling effectiveness measurements involving the PM_{10} inlet tests.

The sampling effectiveness curves simply are drawn smoothly through the data points at present. A statistical model to fit the data has been proposed by Holland and Fitz-Simons in a paper titled "Modeling Particulate Sampling Effectiveness Data" (to be submitted for publication). If this model can accurately fit a wide range of sampling effectiveness data, it should be employed to eliminate the ambiguity of a freehand curve.

SECTION 3

SYSTEM MODIFICATIONS, CHARACTERIZATIONS, AND NEW EQUIPMENT

The wind tunnel at the EPA test facility is a closed loop, recirculating wind tunnel and is shown schematically in Figure 1. The air is moved by a centrifugal blower powered by a 55-hp motor. The speed of the fan is regulated by the action of an alternating current (ac) clutch. The vents and dampers (not shown in the figure) upstream and downstream of the fan are used to control the static pressure in the tunnel. The chiller section is used to remove the heat input from the fan, and, by the combined action of the electrical heaters and the chiller, the temperature can be closely controlled to near ambient. The relative humidity in the wind tunnel is not controlled explicitly. However, the humidity in the wind tunnel is measured daily, and the value is consistently in the range from 50 to 65 percent. Following the turning vanes, the air flow passes through a 6 ft x 6 ft honeycomb flow straightener that has a 4 ft x 4 ft wooden baffle attached to the downstream side. The air enters the 4 ft x 5 ft test section through a reducing section matching the test section dimensions. The test sampler is located 16 ft from the entrance to the test section. The test section is followed by another reducing section to match the return duct dimensions. The air flow then is returned to the fan through an inoperative baghouse.

The test sections were fabricated out of aluminum framing and use Plexiglas side panels for visibility. The floor and the ceiling are made of 3/4-in plywood. Three separate sections comprise the overall test area. Ports for sampling probes and feed-throughs are provided at 6-in intervals along the side posts of the aluminum framing.

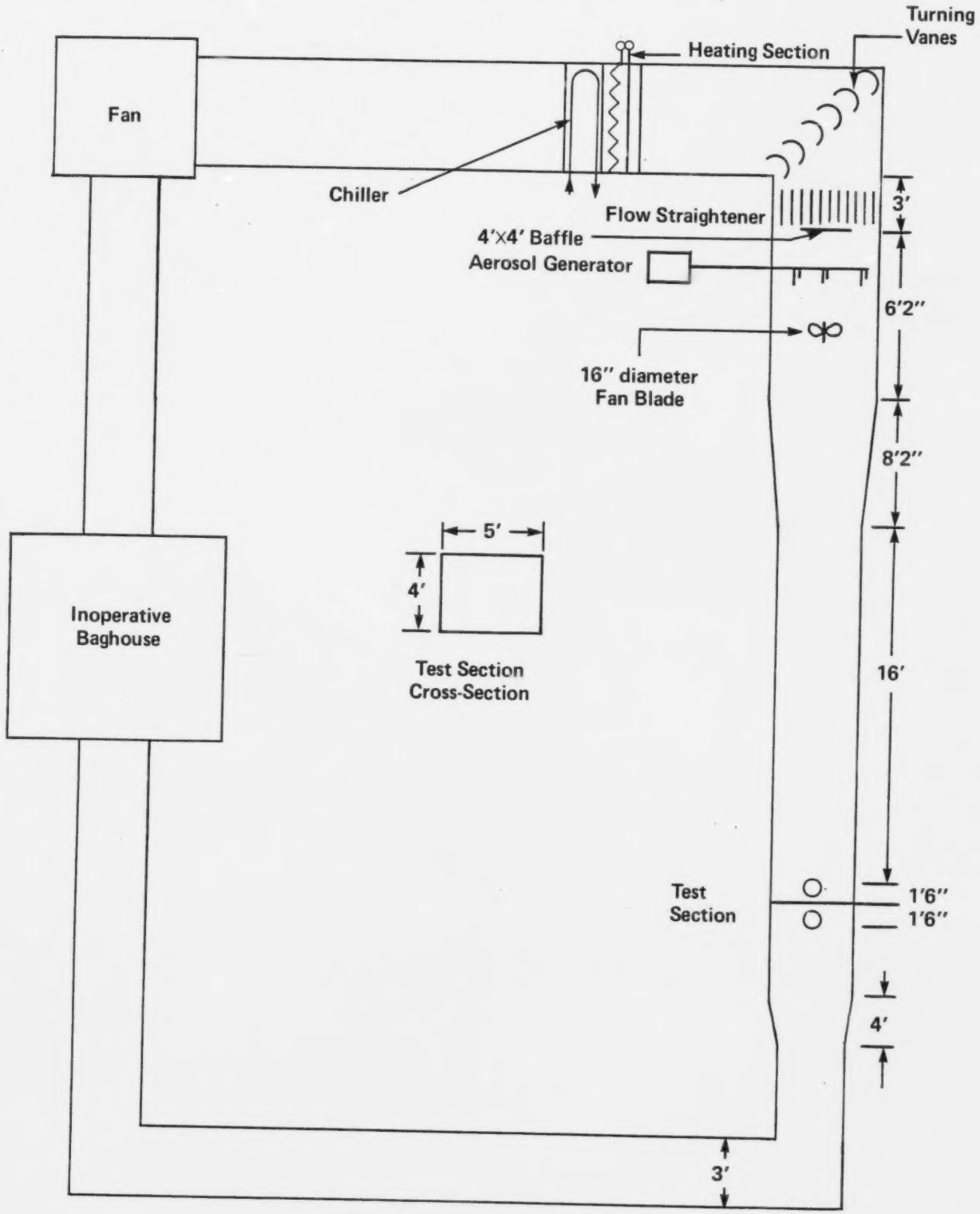


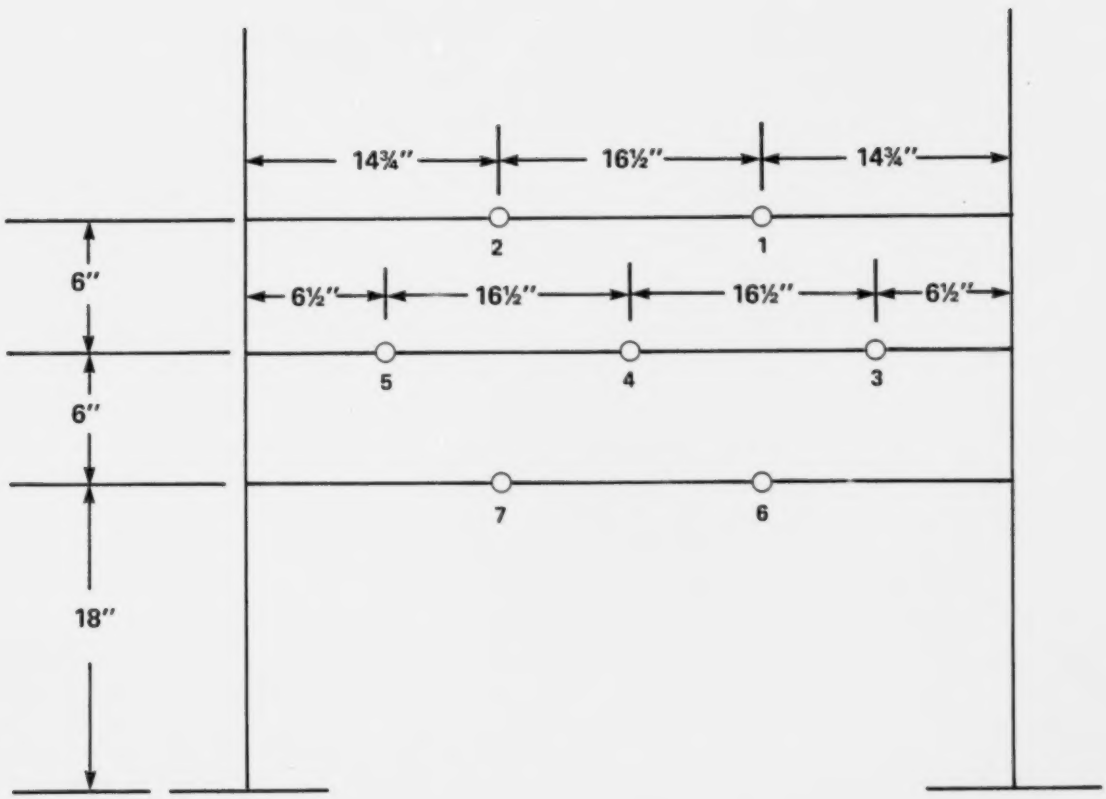
Figure 1. Wind tunnel schematic plan.

3.1 AEROSOL CLOUD UNIFORMITY

The proposed 40 CFR Part 53 requirements pertaining to wind tunnel tests of PM_{10} inlets include a specification for the allowable maximum deviation in aerosol concentration in close proximity to the test sampler. Specifically, 40 CFR Part 53 requires that an array of not less than five evenly spaced isokinetic samplers be used to determine the particle concentration profile in the sampling zone of the wind tunnel. The variation in particle concentration in the sampling zone may not exceed 10 percent of the mean concentration. The sampling zone is defined as a rectangular area having a horizontal dimension of not less than 1.2 times the width of the test sampler at its inlet opening and a vertical dimension not less than 3 times the height of the test sampler's inlet opening. An array of seven evenly spaced isokinetic samplers (called a rake) covering an area that is 33 in wide by 12 in high is used at the EPA wind tunnel. The present rake configuration is illustrated in Figure 2.

The aerosol dispersion system used at the EPA wind tunnel facility in January 1985 provided acceptable concentration profiles at windspeeds of 2 and 8 km/h, but it did not provide a uniformly distributed aerosol cloud at a windspeed of 24 km/h. The original dispersion system consisted of a single injection point located at the center of the wind tunnel and 20 ft upstream of the sampling zone, a 3.5 ft x 3.5 ft baffle located 4 ft upstream of the injection point, and a 7 in diameter fan located 4 in downstream of the injection point and directed into the bulk air flow. All aerosol generation equipment was situated inside the wind tunnel. Modifications were made to the original dispersion system so aerosol cloud uniformity could be achieved at all windspeeds and particle sizes using a single aerosol injection system. The changes made and the ultimate configuration used are summarized below.

Using the original dispersion system, the aerosol concentration was high at the center of the wind tunnel and low near the sides at a windspeed of 24 km/h. The first modification consisted of replacing the 7-in fan with a 16-in diameter blade. The aerosol concentration, however, remained high at the center of the wind tunnel and low near the sides at 24 km/h. The fan was removed from the tunnel, and a multiple point injection system was designed and installed. The new distribution system consisted of a ceramic cap that



NOTE: The direction of the air flow is into the plane of the paper.

Figure 2. Isokinetic sampling rake for uniformity characterization.

fit over the end of a Plexiglas tube enclosing a Krypton-85 neutralizer and three flexible hoses that extended from the cap. The flexible tubes made it relatively simple to change the position of the injection points, and a trial and error procedure was used to find the optimum injection locations. No satisfactory combination of positions, however, was found. A fourth injection point was added to the existing distribution system, and through the use of Y-fittings the distributor was made into an eight-point injection system. During the distributor modification process, flow straighteners were added upstream of the injection location, and several baffles of various sizes were made. Test runs using the eight-point distributor and different combinations of baffles were unsuccessful.

The versatility of the distributor was limited by the length of tubing through which large (20 μm aerodynamic diameter) aerosol particles would pass as well as by the length of the neutralizer. These limitations were eliminated by placing the aerosol generator on the floor of the wind tunnel and transporting the generated particles up through the flexible hoses. Although this configuration allowed for a greater range in the vertical placement of the hoses, the particle losses in the distributor proved to be too great. Subsequently, the generation equipment was moved to the roof of the wind tunnel, and a hole was made in the roof to accommodate the neutralizer. The entire neutralizer/distributor apparatus could be raised or lowered to cover the entire vertical dimension of the wind tunnel. At the same time, a rigid (PVC tubing, 1 in inside diameter [id]) six-point distributor was fabricated and installed. In combination with the new injection system, three small baffles (1 ft x 1 ft) were installed upstream of the distributor. Changing the positions of the baffles changed the aerosol cloud profile in the test section. Additionally, a second flow straightener was added downstream from the test section, and the bag filters were removed from the wind tunnel baghouse to promote particle recirculation.

The 16-in diameter dispersion fan again was installed in the wind tunnel, and combinations of the above distribution systems were tried until a system that provided consistent uniform aerosol cloud profiles was found. The final satisfactory design consisted of the rigid six-point distributor, all aerosol generation equipment on the wind tunnel roof, a flow straightener upstream of

the injection points, a 16-in fan downstream of the distributor and pointed into the bulk air flow, and a 4 ft x 4 ft baffle centered 4 ft upstream of the distributor. Uniformity tests were run using this configuration at each of the required windspeeds (2, 8, and 24 km/h) covering a representative range of particle sizes. Data sheets showing representative results of these uniformity tests are included in Appendix A.

3.2 ISOKINETIC RAKE AND ISOKINETIC HIGH-VOLUME SAMPLER CONCENTRATION COMPARISON

The isokinetic rake is used to determine the aerosol concentration profile in the test section, and the isokinetic high-volume sampler is used to determine the "true" wind tunnel aerosol concentration. The rake has been described previously (see Figure 2). The isokinetic high-volume sampler is a single-point sampling instrument operated at a nominal flow rate of 40 cubic feet per minute (ft^3/min). The inlets have square openings with dimensions such that isokinetic conditions are obtained.

The isokinetic rake and isokinetic high-volume sampler each sample the "true" wind tunnel aerosol concentration. Although there is no specification in 40 CFR Part 53 about how close the two must agree, they should ideally yield identical concentration values. However, in practice a discrepancy may exist between the two results. The sampling effectiveness calculation for a candidate inlet requires the measurement of the true wind tunnel aerosol concentration as a reference. Thus, the goal is to minimize the difference between the two methods and then choose the reference that is deemed to be the most reliable.

The two key elements in obtaining accurate aerosol concentration values are making accurate measurements of the air flow rate through the samplers and taking great care in handling and analyzing the filter extractions. The flow rate through each of the seven rake filters is controlled by a critical orifice with a nominal flow rate of 10.8 liters per minute (L/min). This flow is measured periodically using a wet test meter, and the wet test meter flow rate is taken to be that through the orifice. The flow through the isokinetic high-volume sampler is set using the pressure drop across a calibrated orifice and measured during each test using a Dresser 3M Roots Meter. The volumetric flow measured using the Roots Meter is corrected for the system pressure drop

and daily ambient temperature and pressure readings. The isokinetic high-volume sampler has yielded concentration values that are 7 percent higher on average than the isokinetic rake during tests in which both reference concentration measurements have been made. The goal has been to keep agreement to within 10 percent. No data are available from other PM_{10} laboratories that would indicate the quality of agreement attainable.

Choosing one method as the concentration reference requires weighing the relative advantages of each of the two possible methods. The advantages of the rake are that it provides a measure of cloud uniformity and it uses an average of seven concentration values to determine the true concentration. The high-volume sampler also has two main advantages. First, it uses the same size of filter paper as the candidate PM_{10} samplers; therefore, the extraction volumes used are generally the same. Second, both the high-volume and candidate PM_{10} samplers can be operated at the same nominal flow rate, e.g., (40 ft^3/min) for the same length of time (20 min). Based on these relative advantages, the isokinetic high-volume sampler has been chosen as the concentration reference, and all effectiveness values presented in Section 4 of this report are based on the high-volume sampler as the concentration reference.

3.3 REPEATABILITY OF ISOKINETIC CONCENTRATION MEASUREMENTS AND CONCENTRATION EFFECTS OF STOPPING THE WIND TUNNEL FAN BETWEEN RUNS

No specification was proposed in 40 CFR Part 53 concerning the maximum allowable variability in replicate isokinetic sampler measurements. However, because a typical test sequence process in the order 10-μm inlet, high-volume isokinetic, 10-μm inlet, two test inlets are referenced to the same isokinetic measurement. It is therefore necessary to know if there is any time dependence of measured concentration values. Also, because it is necessary to turn off the wind tunnel fan when installing or removing test samplers and inlets from the wind tunnel, any concentration effect caused by stopping the fan between isokinetic sampler runs is important. The variability of replicate concentration measurements was investigated by measuring the wind tunnel aerosol concentration using the isokinetic high-volume sampler in consecutive 20-min runs. The wind tunnel fan was stopped between several of the runs to examine the effect it had on subsequent concentration measurements.

Figures 3, 4, and 5 contain the results of this study at 2, 8, and 24 km/h, respectively. The concentration stability at 2 km/h was tested using 5 μm liquid particles. After particle generation began, the wind tunnel was allowed to run for 15 min before the first isokinetic sampler test was made. The wind tunnel fan was allowed to run while the filter paper was replaced in the isokinetic sampler between runs 1 and 2 and again between runs 2 and 3. After run 3, the wind tunnel fan was turned off while the filter paper was replaced. After about 5 min (the length of time needed to replace the filter paper and return the sampler to the wind tunnel), the fan again was started and a fourth isokinetic sampler run was performed. The sequence at 8 km/h (using 20 μm particles) consisted of running the wind tunnel fan for 5 min after particle generation began and then starting the first isokinetic sampler run. The fan continued to run between runs 1 and 2, but was stopped for 5 min between runs 2 and 3 and stopped again for 5 min between runs 3 and 4. After run number 4, the fan was allowed to continue running and a fifth isokinetic sampler measurement was performed. Finally, at 24 km/h (using 10 μm particles), the test sequence was to run the fan for 5 min before taking the first isokinetic measurement. The fan remained on between runs 1 and 2 and again between runs 2 and 3. The fan was stopped for 5 min after run 3 and stopped again for 5 min after run 4.

The average concentration, standard deviation, and coefficient of variation (the standard deviation expressed as a percentage of the mean) are presented in Table 1. The coefficient of variation was less than 3 percent at all three windspeeds, and the isokinetic measurements taken after stopping the wind tunnel fan all fell within one standard deviation of their respective means except in one case where the isokinetic value was within two standard deviations of the mean. The concentration reproducibility is excellent, and the effect of stopping the wind tunnel fan between runs appears to be negligible.

3.4 PROCEDURAL CHANGES AND NEW EQUIPMENT

Several changes have been made to the procedures for testing candidate PM_{10} inlets, and new equipment has been purchased in support of the wind tunnel operation. The procedural changes were made to improve the accuracy and reliability of the test results. The new equipment was purchased to improve the quality of the test results and to simplify the test procedures.

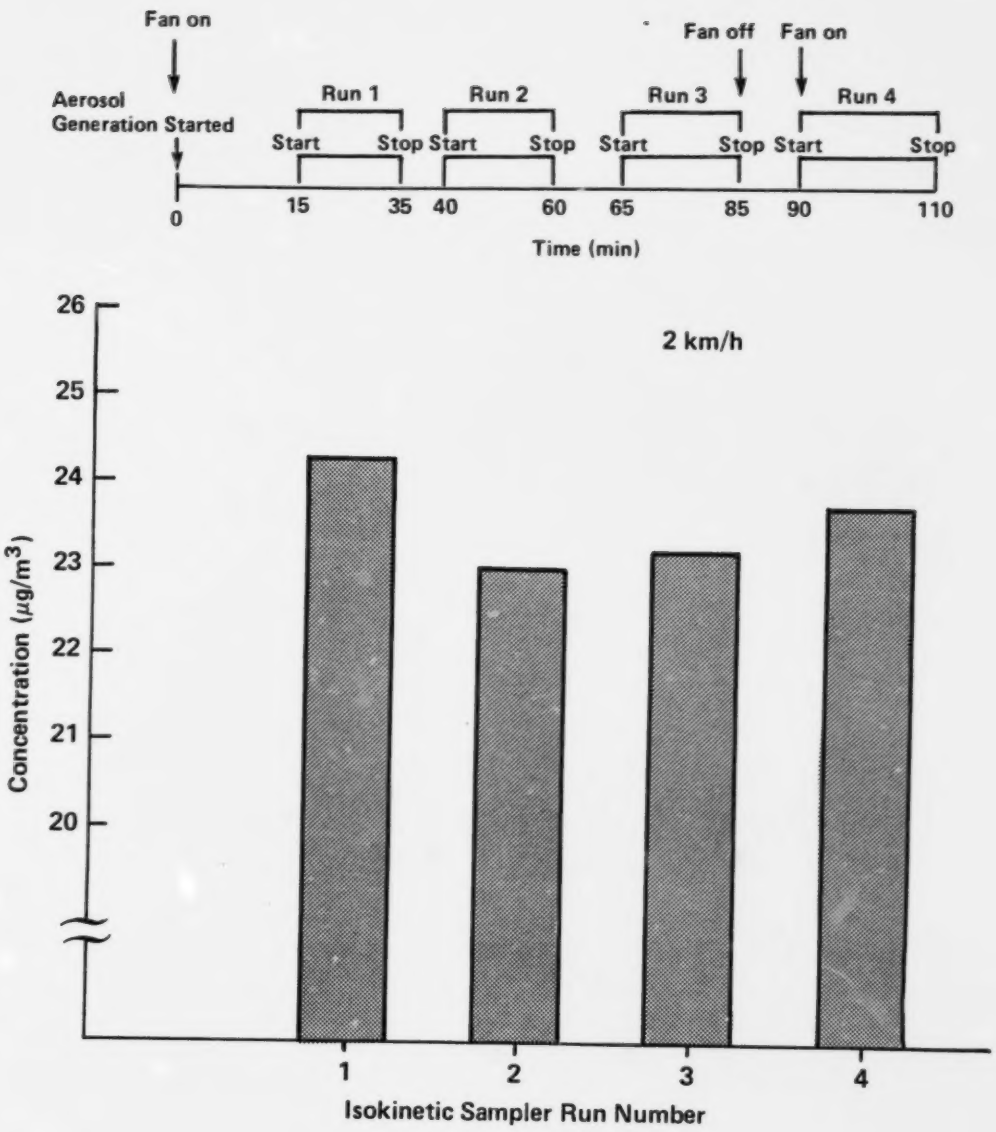


Figure 3. Variability of concentration measurements using the isokinetic high-volume sampler at a windspeed of 2 km/h.

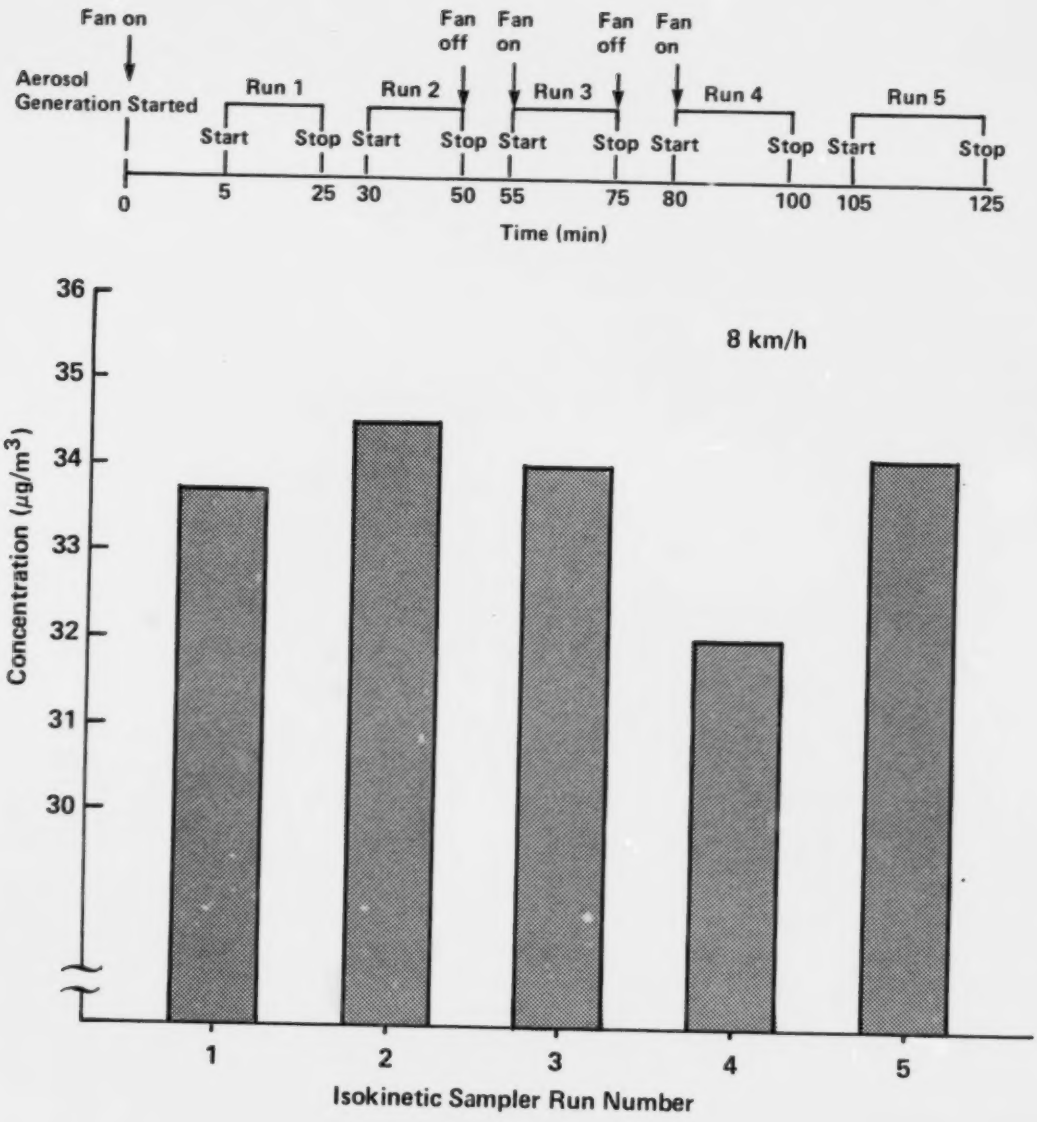


Figure 4. Variability of concentration measurements using the isokinetic high-volume sampler at a windspeed of 8 km/h.

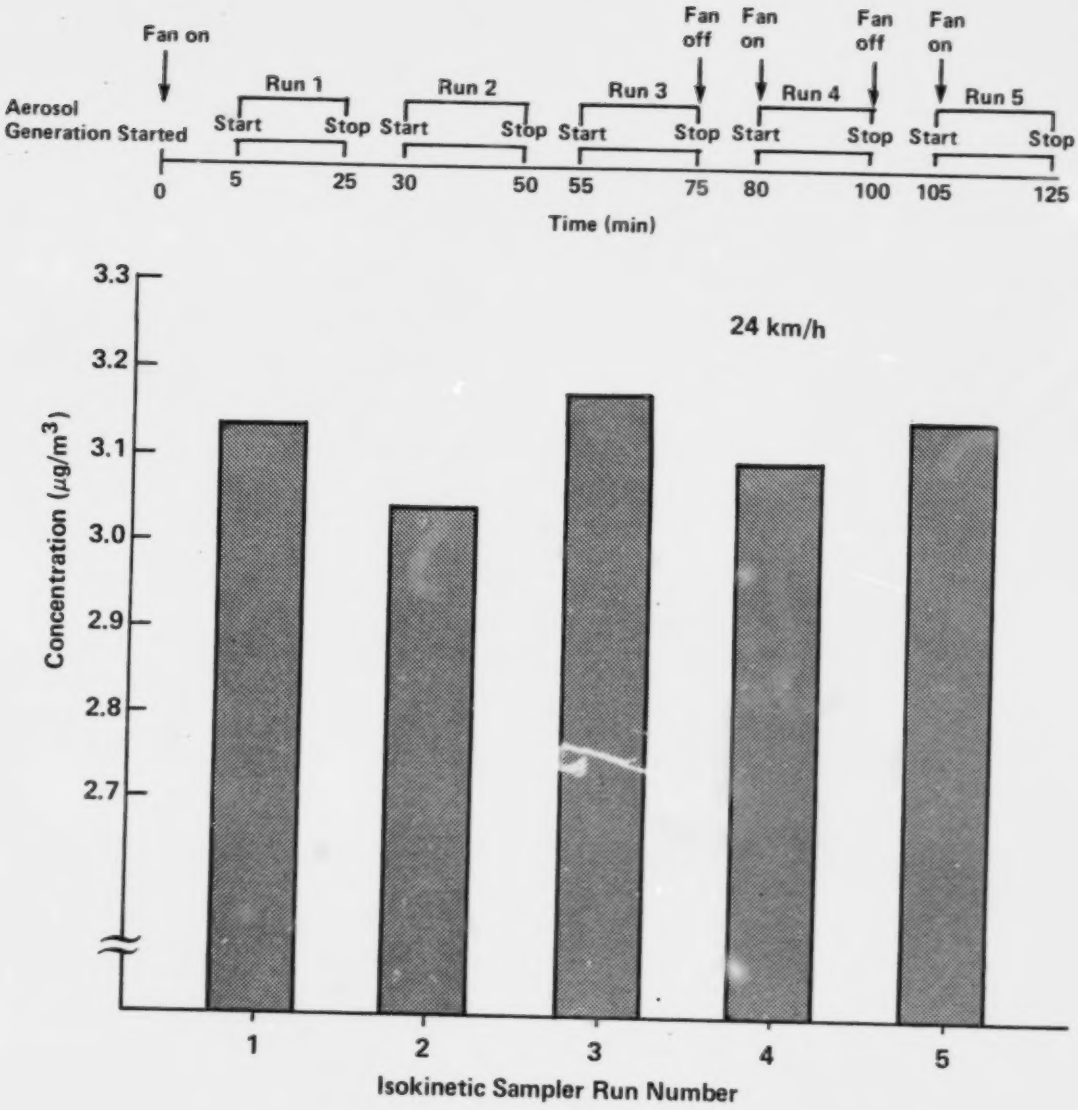


Figure 5. Variability of concentration measurements using the isokinetic high-volume sampler at a windspeed of 24 km/h.

TABLE 1. CONCENTRATION VARIABILITY BETWEEN REPLICATE ISOKINETIC SAMPLER RUNS

Windspeed (km/h)	Particle size (μm)	Avg. conc. ($\mu g/m^3$)	Std. dev. ($\mu g/m^3$)	Coeff. of var. (%)
2	5	23.5	0.56	2.4
8	20	33.66	0.97	2.9
24	10	3.12	0.05	1.6

The first procedural change was to wash the internal surfaces of the rake nozzles and the isokinetic high-volume sampler inlets with the appropriate extraction solution (NaOH for liquid particles and NH_4OH for solid particles) to account for the particles that deposit within the inlets. The rake nozzles are washed with 18 milliliters (mL) of extraction solution, and the isokinetic high-volume sampler inlets are washed with 500 mL of extraction solution. These wash solutions are analyzed fluorometrically, and the wash concentrations are included in the effectiveness calculation. The second procedural change consisted of measuring the flow rate of the aerosol solution to the aerosol generator. Digital calipers are used to measure the displacement of the syringe containing the aerosol solution. The feed rate is required in the calculation of particle size as is the frequency of the electrical signal applied to the generator crystal and the aerosol solution composition. An accurate value for the generator feed rate is necessary to calculate accurately the particle size generated. Additionally, the periodic measurement of syringe displacement acts as a check on the successful operation of the generator.

The primary piece of new equipment purchased for the wind tunnel operation was an SLM Aminco Fluoro-Colorimeter II. The new fluorometer provides a digital readout, an automatic offset for blank readings, and automatic ranging covering four decades of concentration. The precision of the fluorometer is discussed in Section 3.5. Additionally, new single piece rake nozzles were fabricated to replace the old two-piece design. The single piece nozzles make the nozzle wash procedure an easier operation. Also, new isokinetic high-volume sampler inlets were fabricated. The new inlets were redesigned so the gasket forming the seal between the filter and inlet would fit flush with the inside edge of the inlet. Previously, the gasket overlapped the inlet edge and covered slightly more of the filter paper than the inlet itself covered. These changes were completed before the concentration comparisons reported in Sections 3.2 and 3.3 were made.

3.5 FLUOROMETER PRECISION

In 40 CFR Part 53, the relative error of the analytical technique used to determine the wind tunnel particle concentration must be less than 5 percent. Relative error is defined as:

$$RE = (p \times 100\%)/(x) \quad (1)$$

where

p = instrument precision (μg/mL)

x = measured concentration (μg/mL).

The analytical technique used at the EPA wind tunnel facility is fluorometry, and the instrument used is an SLM Aminco Fluoro-Colorimeter II. The precision of the fluorometer was determined over its range of operation using solutions of uranine in 0.1 N NaOH at concentrations of 1, 0.1, 0.01, and 0.001 μg/mL. Six samples were prepared at each concentration using a procedure that mimics the procedures used to handle filter samples from an actual inlet test. First, a 47-mm Gelman Type AE glass fiber filter was placed in a sample bottle along with 18 mL of the appropriate uranine solution. The sample bottles were sonicated for 15 min, and then a cuvette full of each sample was centrifuged for 7 min per standard operating procedures. Readings were obtained for each solution concentration and are shown in Table 2, along with the corresponding uranine concentration (obtained from the fluorometer calibration curve shown in Figure 6), the standard deviation, and relative error of the results. Figure 7 contains a plot of relative error versus uranine concentration. The uranine concentration corresponding to a relative error of 5 percent is 0.014 μg/mL. Uranine concentrations collected by the rake or isokinetic high-volume sampler depend on both the particle size and on the windspeed in the wind tunnel. In general, as particle size decreases, the quantity of uranine also decreases. Also, the greater the windspeed, the more dilute the uranine concentration in the tunnel.

The performance of the fluorometer comes into question only when running 3 or 5 μm particles at a windspeed of 24 km/h. A new rake flow system is under construction at this time so greater quantities of uranine may be collected on the rake filters in the same amount of sampling time. This will put the fluorometer operation in the acceptable range for all combinations of windspeed and particle size. The rake nozzle and isokinetic inlet washes have uranine concentrations as low as 0.001 μg/mL. However, because the wash concentrations are such a small percentage of the total concentration, the higher fluorometer relative error is considered to be acceptable.

TABLE 2. RESULTS FROM THE FLUOROMETER PRECISION STUDY

Fluorometer reading	Uranine concentration (μg/mL)	Average uranine concentration (μg/mL)	Standard deviation (μg/mL)	Relative error (%)
2.71	1.031			
2.72	1.035			
2.70	1.027			
2.71	1.031			
2.71	1.031			
2.72	1.035	1.032	0.00301	0.292
0.260	0.098			
0.265	0.100			
0.261	0.099			
0.263	0.100			
0.258	0.098			
0.262	0.099	0.099	0.000894	0.903
0.0276	0.010			
0.0232	0.009			
0.0262	0.010			
0.0294	0.011			
0.0249	0.009			
0.0272	0.010	0.00983	0.000753	7.66
0.0026	0.000985			
0.0016	0.00060			
0.0053	0.0020			
0.0010	0.00037			
0.0091	0.0034			
0.0046	0.0017	0.00151	0.00113	74.8

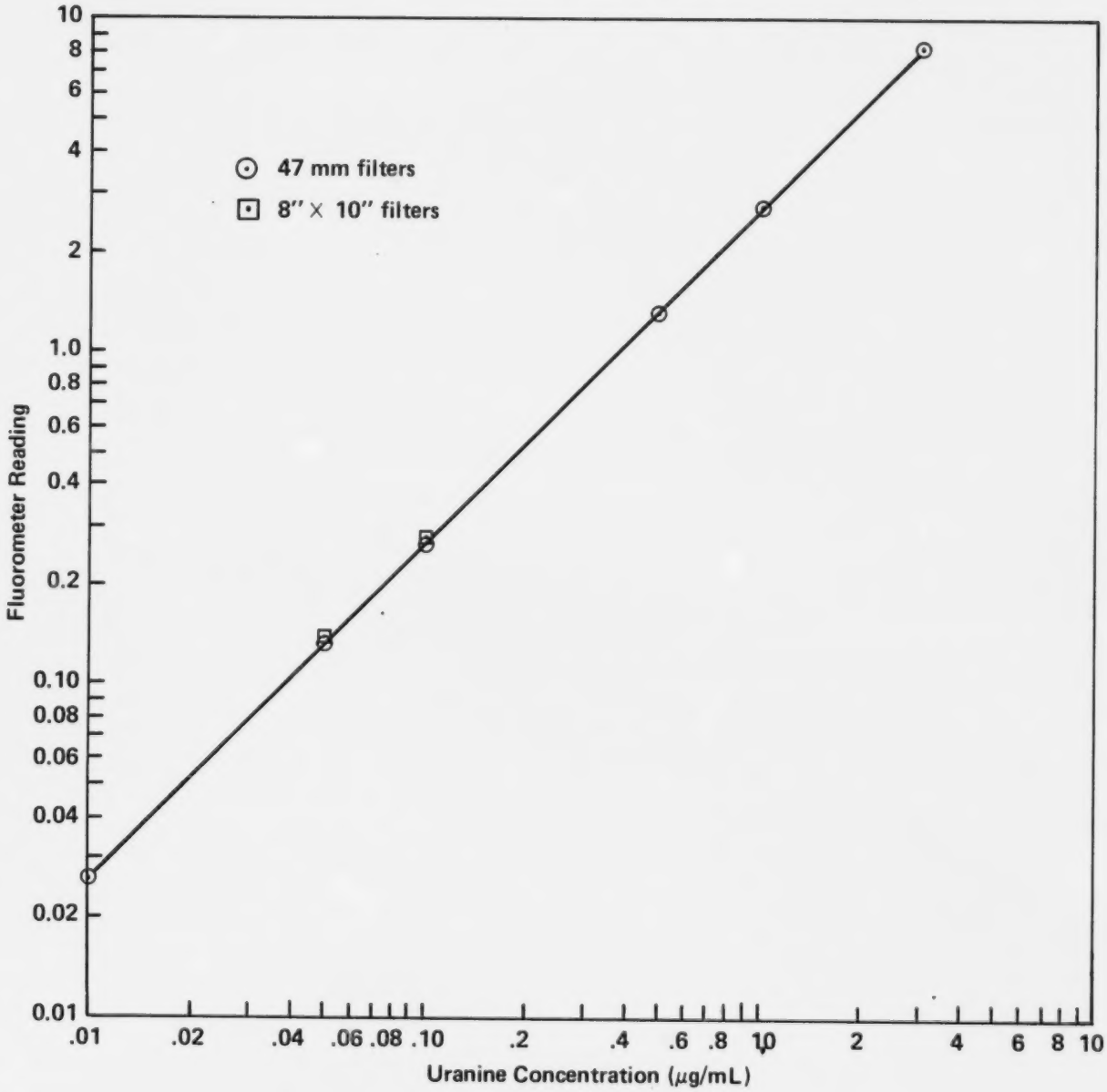


Figure 6. Liquid particle fluorometer calibration curve.

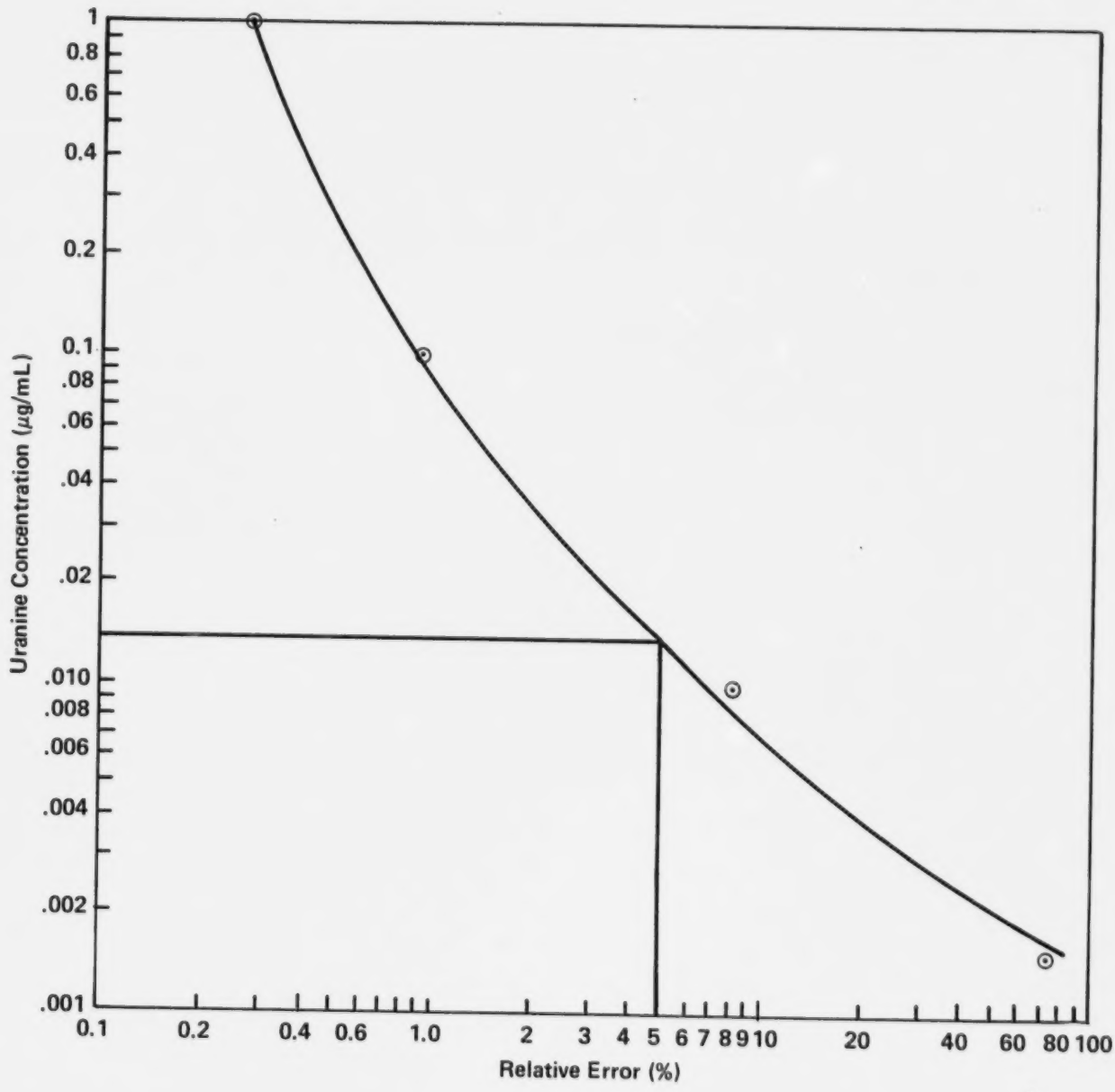


Figure 7. Fluorometer relative error at measured uranine concentrations.

3.6 VELOCITY AND TURBULENCE PROFILES

The proposed 40 CFR Part 53 requires both air velocity and turbulence intensity measurements to characterize the wind tunnel air flow. The air velocity is required to be ±10 percent of the mean windspeed throughout the sampling zone of the test section. The turbulence intensity must be measured and recorded although there are no specifications for either the magnitude or macroscale of the turbulence.

windspeed and turbulence intensity were measured using a TSI System 1050-1 Anemometer and a ruggedized probe along with a TSI Model 1056 RMS, mean-square, direct current (dc) voltmeter. The probe was calibrated on a TSI Model 1125 calibrator, and the calibration curve was linearized using the coefficients from a 4th order least squares polynomial fit of the original data. The calibration curve and linearized response both are shown in Figure 8.

Three ports located at the centerline of the east side vertical wall and at 6-in intervals above and below the centerline were used to insert the velocity probe into the air flow. Measurements were taken at a distance of 6 in from the east wind tunnel wall and at 12-in intervals to a distance of 54 in from the east wall. Over the course of several weeks, complete velocity and turbulence profiles were measured three times each at windspeeds of 2, 8, and 24 km/n. Figures 9, 10, and 11 compare the velocity and turbulence intensity measurements taken at 8 km/h on three separate days at locations 6 in. above the vertical centerline, at the centerline, and 6 in below the vertical centerline, respectively. At a given point, the maximum deviation from the daily mean windspeed measurements was 1.7 percent, and the maximum deviation in turbulence intensity at a given point was 1.0 percent. Figures 12 and 13 contain typical velocity and turbulence profiles obtained at 2 and 24 km/h, respectively.

Based on the reproducibility of the daily measurements, complete profiles of air velocity and turbulence intensity are not required on a daily basis. Rather, the centerline velocity profile is obtained and used to verify that a sufficient reproduction of the original profile has been obtained.

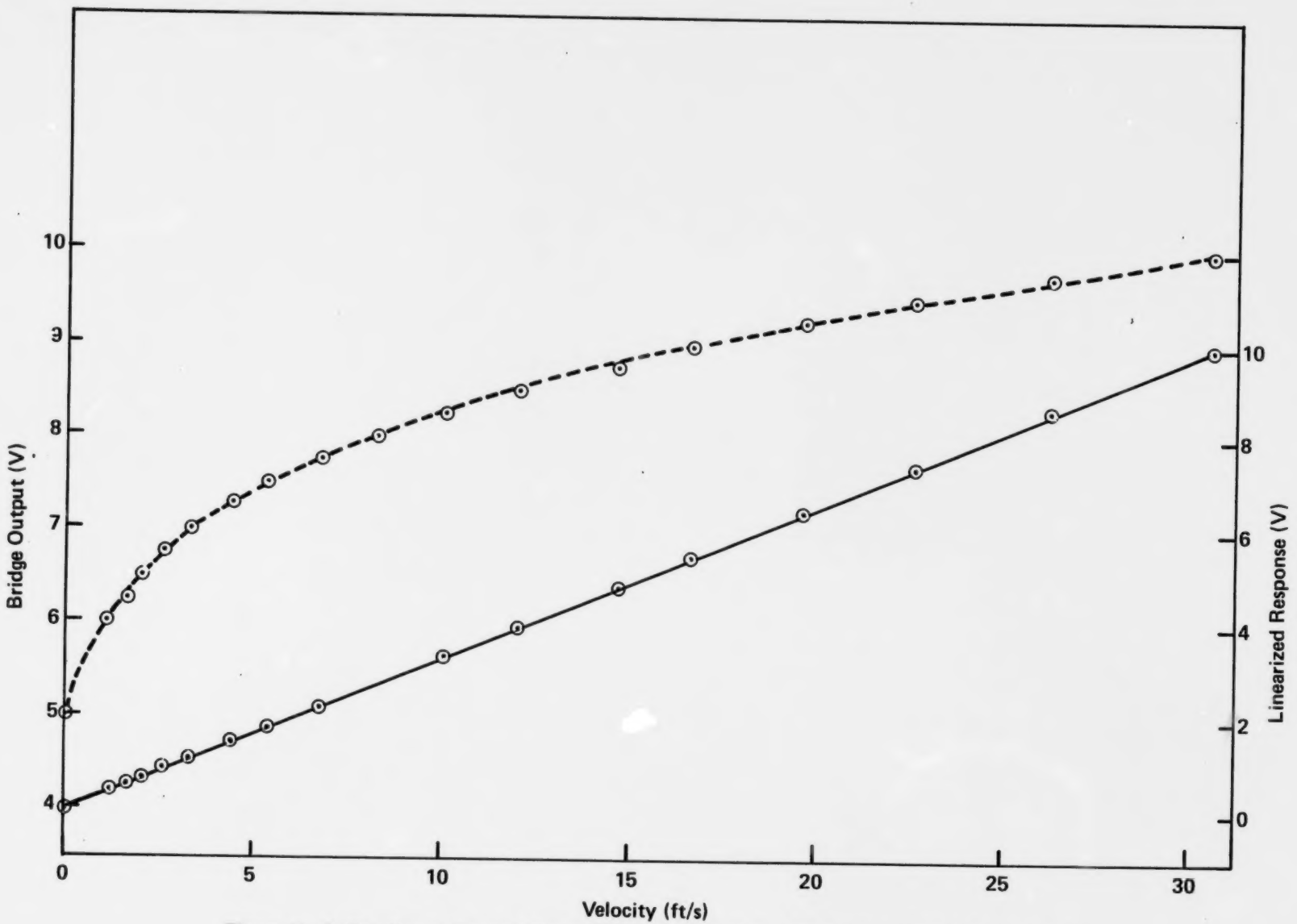
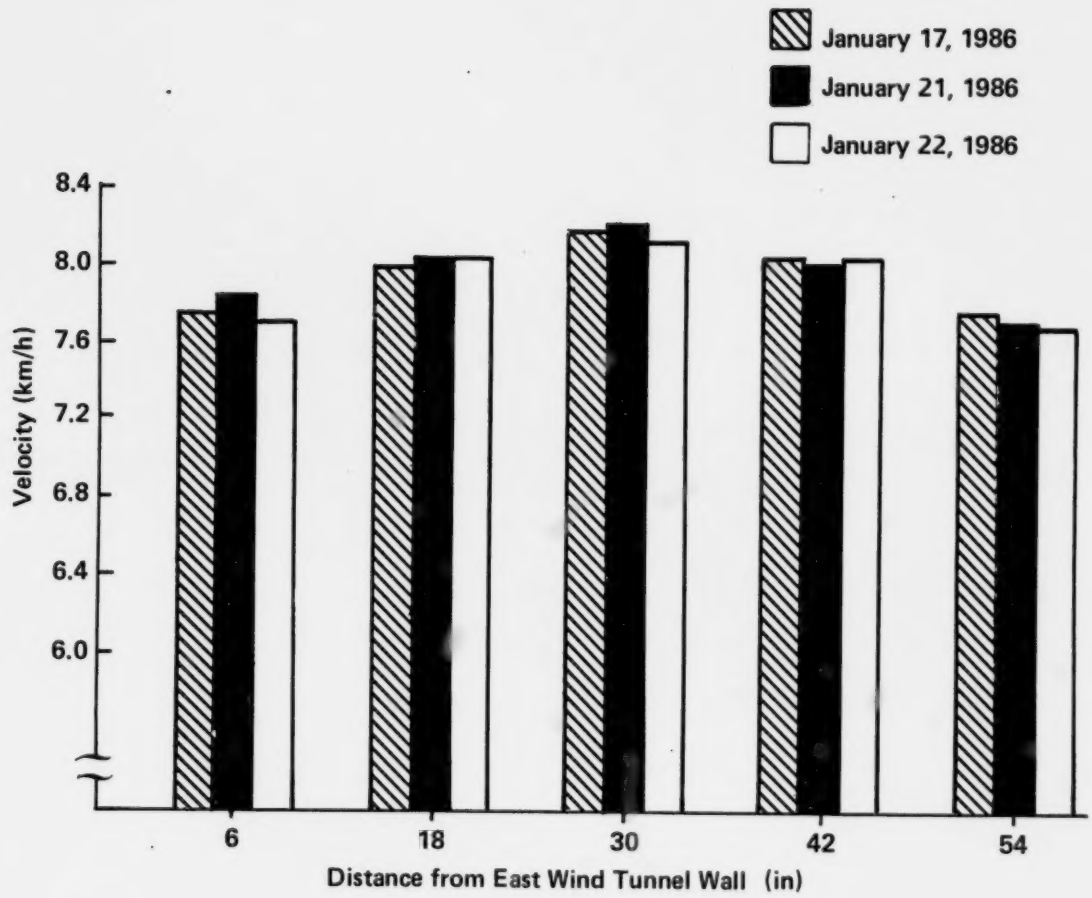


Figure 8. Calibration curve and linearized response of the TSI System 1050-1 Anemometer.



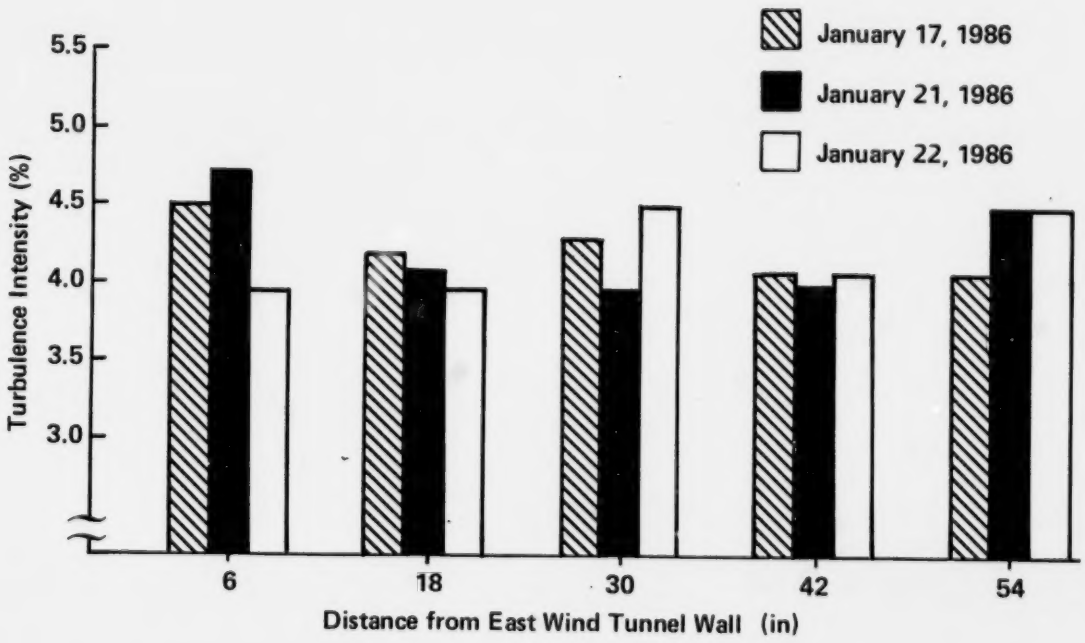
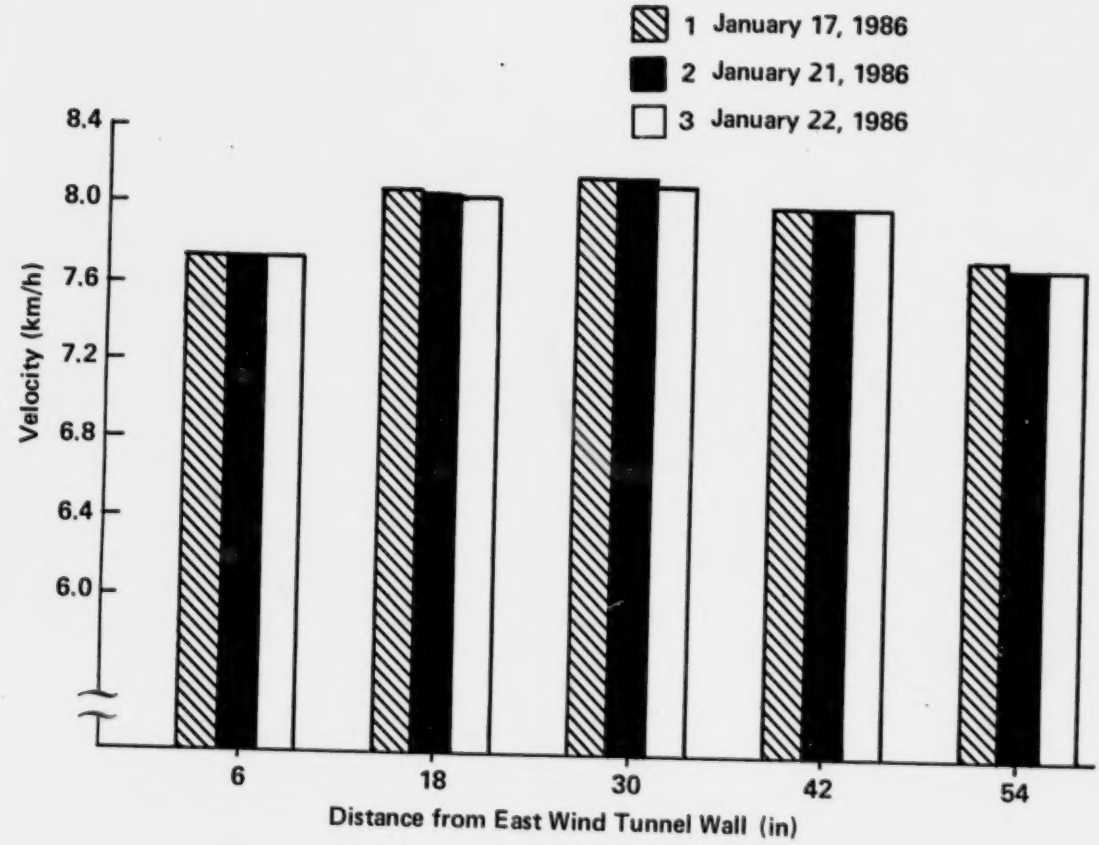


Figure 9. Velocity and turbulence profiles taken 6 in above the vertical centerline on three consecutive days.



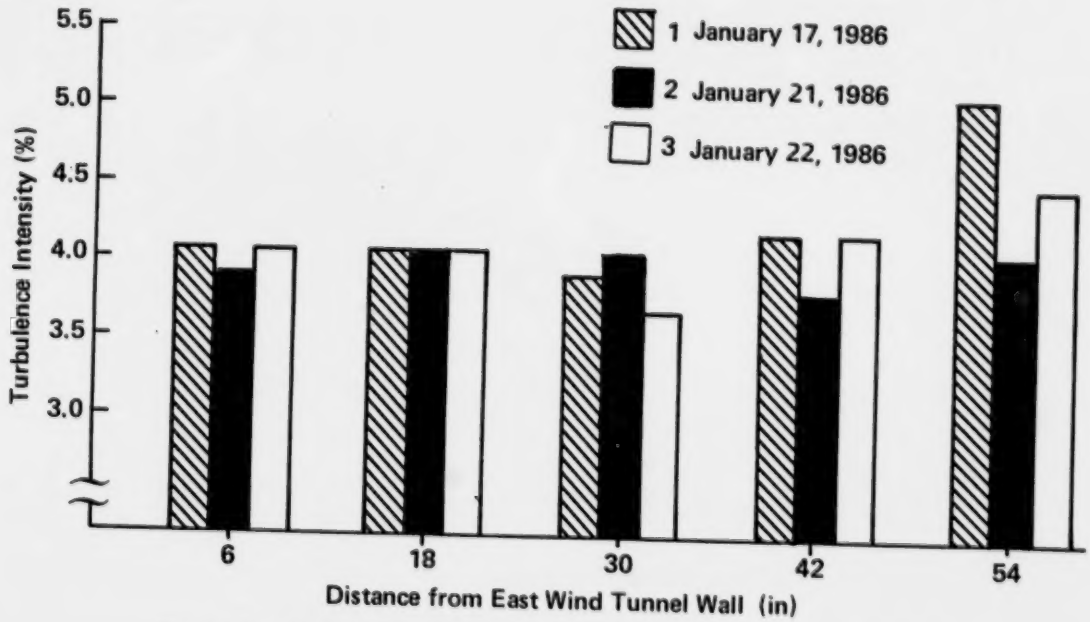
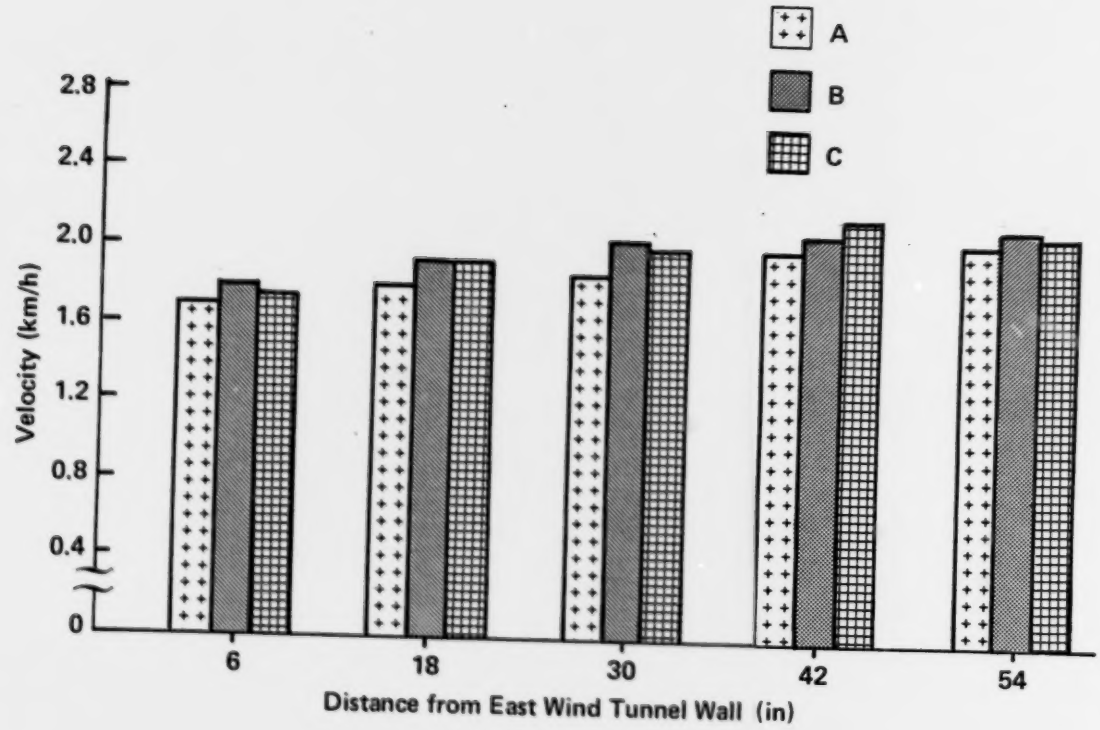


Figure 11. Velocity and turbulence profiles taken 6 in below the vertical centerline on three consecutive days.



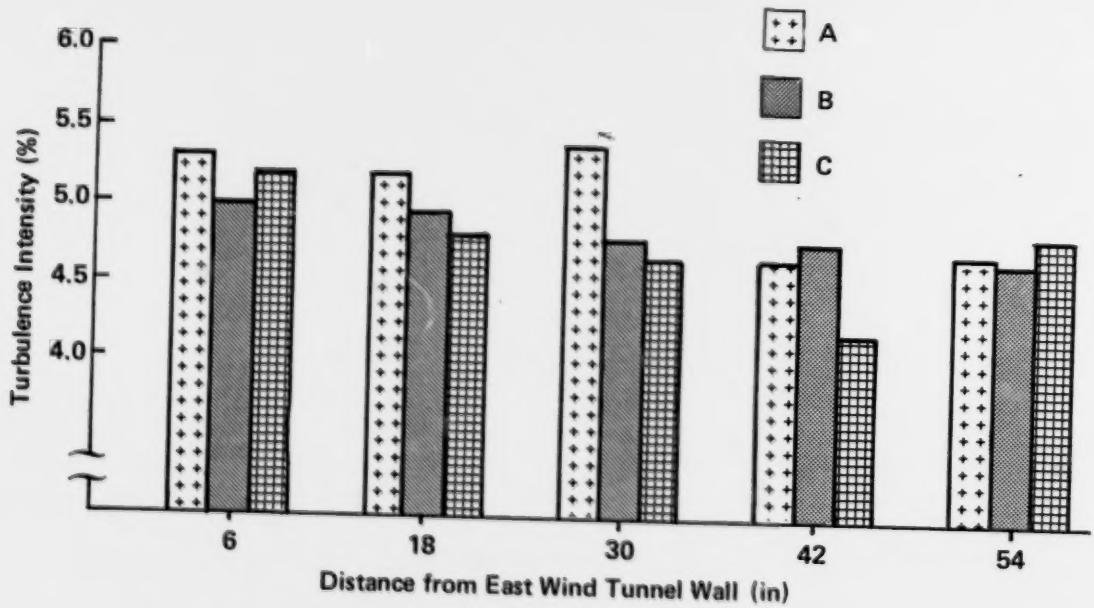
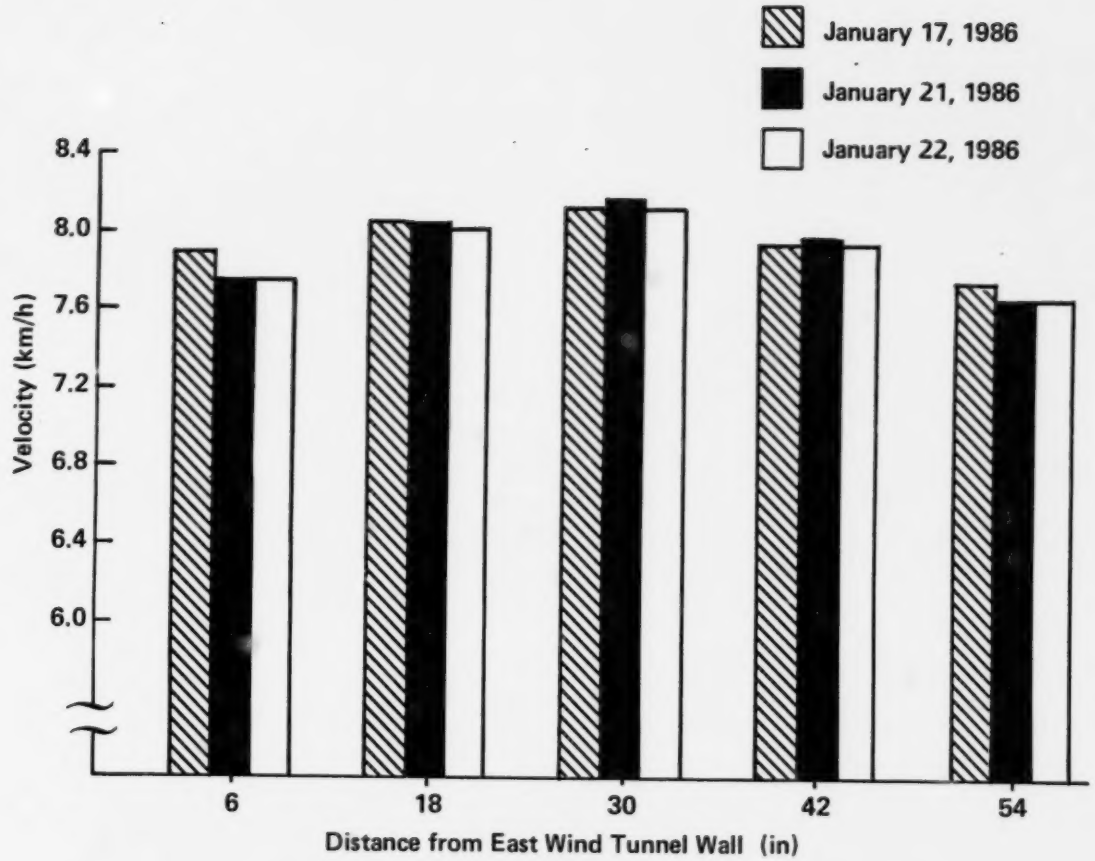


Figure 12. Typical velocity and turbulence profiles taken at (A) 6 in above the vertical centerline, (B) the vertical centerline, and (CC) 6 in below the vertical centerline for a windspeed of 2 km/h.



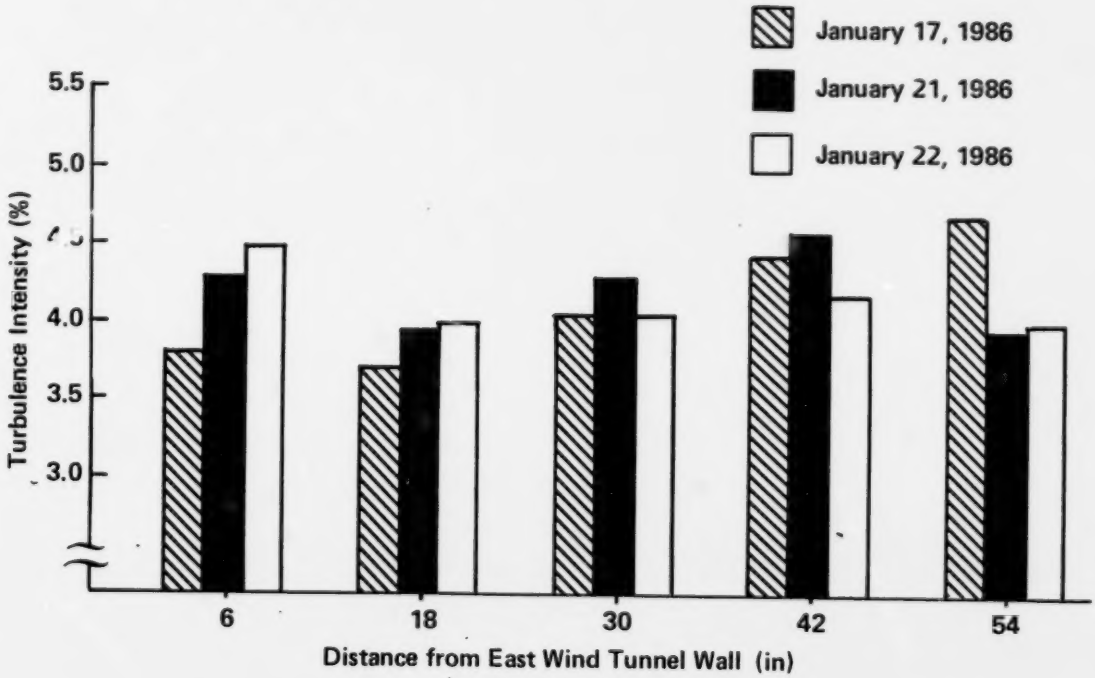
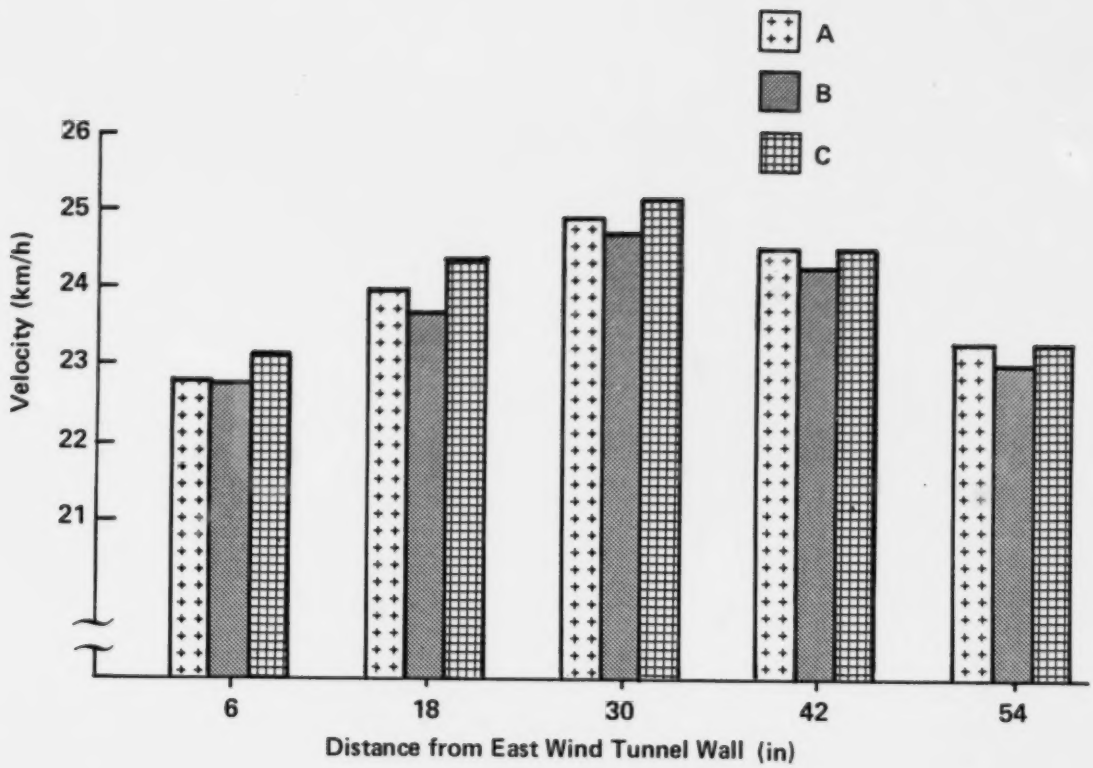


Figure 10. Velocity and turbulence profiles taken at the vertical centerline on three consecutive days.



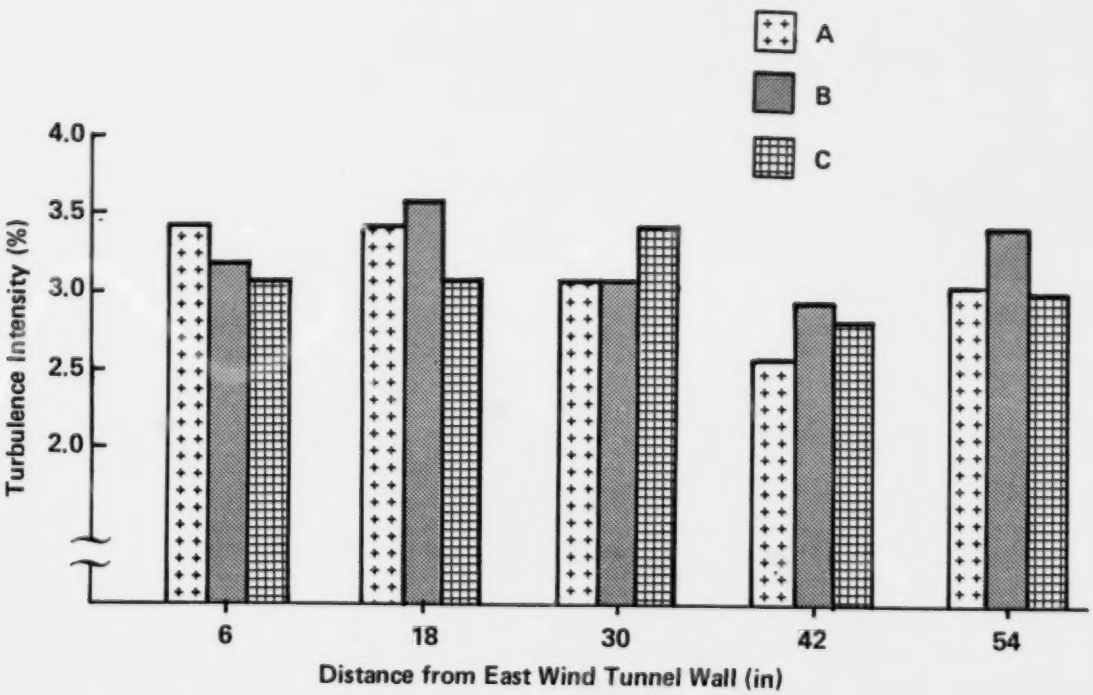


Figure 13. Typical velocity and turbulence profiles taken at (A) 6 in above the vertical centerline, (B) the vertical centerline, and (C) 6 in below the vertical centerline for a windspeed of 24 km/h.

SECTION 4

RESULTS OF THE PM_{10} INLET TESTS

PM_{10} inlet tests were resumed in January 1986. The Wedding IP_{10} SSI was tested at a windspeed of 8 km/h using both liquid and solid aerosol particles. This was a preliminary test designed chiefly to determine if all procedural and operational changes were satisfactory. Following this preliminary test, the Wedding IP_{10} SSI and Andersen Samplers Model 321A SSI were tested sequentially using both solid and liquid aerosol particles at windspeeds of 2 and 8 km/h. A "dirty" field-tested Wedding IP_{10} SSI then was tested sequentially with the "clean" Wedding SSI used in the previous wind tunnel tests at 2 km/h with liquid particles. Sequential liquid particle tests then were conducted at 8 km/h on a cleaned field test Wedding IP_{10} SSI and the "clean" Wedding IP_{10} reference inlet. Results from the Phoenix III field study have been summarized in "Intercomparison of High-Volume PM_{10} Samplers at a Site with High Particulate Concentrations" (JAPCA, Vol. 36, No. 8, pp. 917-920, 1986), which also contains a comparison of wind tunnel test results with the field test results.

Many of the above inlet tests were abbreviated and did not consist of the entire range of particle sizes required in the FRM. Test points at both small (3 and 5 μm) and large (15 and 20 μm) particle diameters were eliminated.* The sampling effectiveness curves were nonetheless extrapolated beyond the actual test points. The extrapolations made expected mass calculations possible for the test inlets. Small deviations in the extrapolations would have a minimal effect on the expected mass calculation.

Interim reports covering the results of the above wind tunnel tests were prepared at the completion of each test. These reports follow in their entirety. Much of the background and procedural information presented in each

*Note that micrometer (μm) and micron (μ) are equivalent units of measurement. However, micron is now considered to be obsolete.

report is repetitious; however, the reports are left intact so that any one of the interim reports can be removed from the others and still be self-explanatory. For the same reason, the table and figure numbers have been left intact and do not appear in the list of tables or the list of figures. The reports are numbered consecutively, and a total of 13 tests had been performed prior to January 1986. The first test reported here is number 14.

4.1 EPA WIND TUNNEL TEST REPORT NO.14: A PRELIMINARY EVALUATION OF THE WEDDING IP_{10} SIZE SELECTIVE INLET AT A WINDSPEED OF 8 km/h: LIQUID AND SOLID PARTICLES

ABSTRACT

The Wedding IP_{10} size selective inlet was tested at a windspeed of 8 km/h using both liquid and solid aerosol particles at the EPA wind tunnel test facility. The primary purpose of this test was to validate the procedural and operational changes made at the wind tunnel over the previous year. These tests will be repeated during concurrent testing of the Wedding IP_{10} and Andersen Model 321A inlets. Therefore, this report has been purposely abbreviated.

Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with liquid aerosol particles composed of oleic acid tagged with a uranine tracer and also with solid particles composed of ammonium fluorescein. Nine liquid particle tests covering the size range from 3 to 20 μm were performed and five solid particle tests covering the size range from 5 to 20 μm were performed. Based on the results of these tests, the Wedding IP_{10} inlet meets the proposed specifications for 50-percent cutpoint, liquid particle sampling effectiveness, and solid particle sampling effectiveness.

AN EVALUATION OF THE WEDDING IP_{10} SIZE SELECTIVE INLET

RESULTS

The liquid and solid particle effectiveness values and a summary of run results appear in Table 1 for the Wedding IP_{10} inlet. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the liquid particle sampling effectiveness curve for the Wedding IP_{10} inlet. The solid particle points also are shown for comparison. From Figure 1 it is seen that the D_{50} cutpoint for the Wedding inlet is 9.2 μm. The slope of the curve, estimated by the parameter $\sigma_g = (D_{16}/D_{84})^{1/2}$, is 1.37 for the Wedding inlet. An integration of the effectiveness curve was performed against an assumed aerosol size distribution, and the resultant expected mass was compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D3.) The ratio of the expected mass for the Wedding IP_{10} Inlet to the mass predicted for the ideal sampler is 0.976.

CONCLUSIONS

Based on this study, the Wedding IP_{10} size selective inlet meets the specifications for 50-percent cutpoint, liquid particle sampling effectiveness, and solid particle sampling effectiveness.

TABLE 1. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size	Penetration (%)	CV (%)	Rake filter/ ISO filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.0 (L)	99.0	8.1	1.70	1.09	2.9
5.0 (L)	89.3	2.1	1.20	1.12	5.2
6.9 (L)	79.3	3.2	1.10	1.06	4.5
9.2 (L)	49.7	3.9	1.00	1.05	2.2
10.0 (L)	33.0	3.0	1.09	1.03	5.0
11.2 (L)	22.2	6.6	1.02	0.99	4.3
13.5 (L)	7.5	32.4	1.00	1.02	3.8
14.6 (L)	4.8	8.3	1.02	0.99	3.7
18.7 (L)	3.6	21.0	1.11	1.04	3.8
5.2 (S)	88.0	5.3	1.10	1.05	2.3
7.2 (S)	78.6	9.6	1.04	1.03	4.6
9.8 (S)	42.0	6.1	1.15	1.04	2.8
13.5 (S)	6.7	2.3	1.18	1.08	3.3
20.0 (S)	6.6	9.3	0.94	1.05	6.6

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

(L) = Liquid.

(S) = Solid.

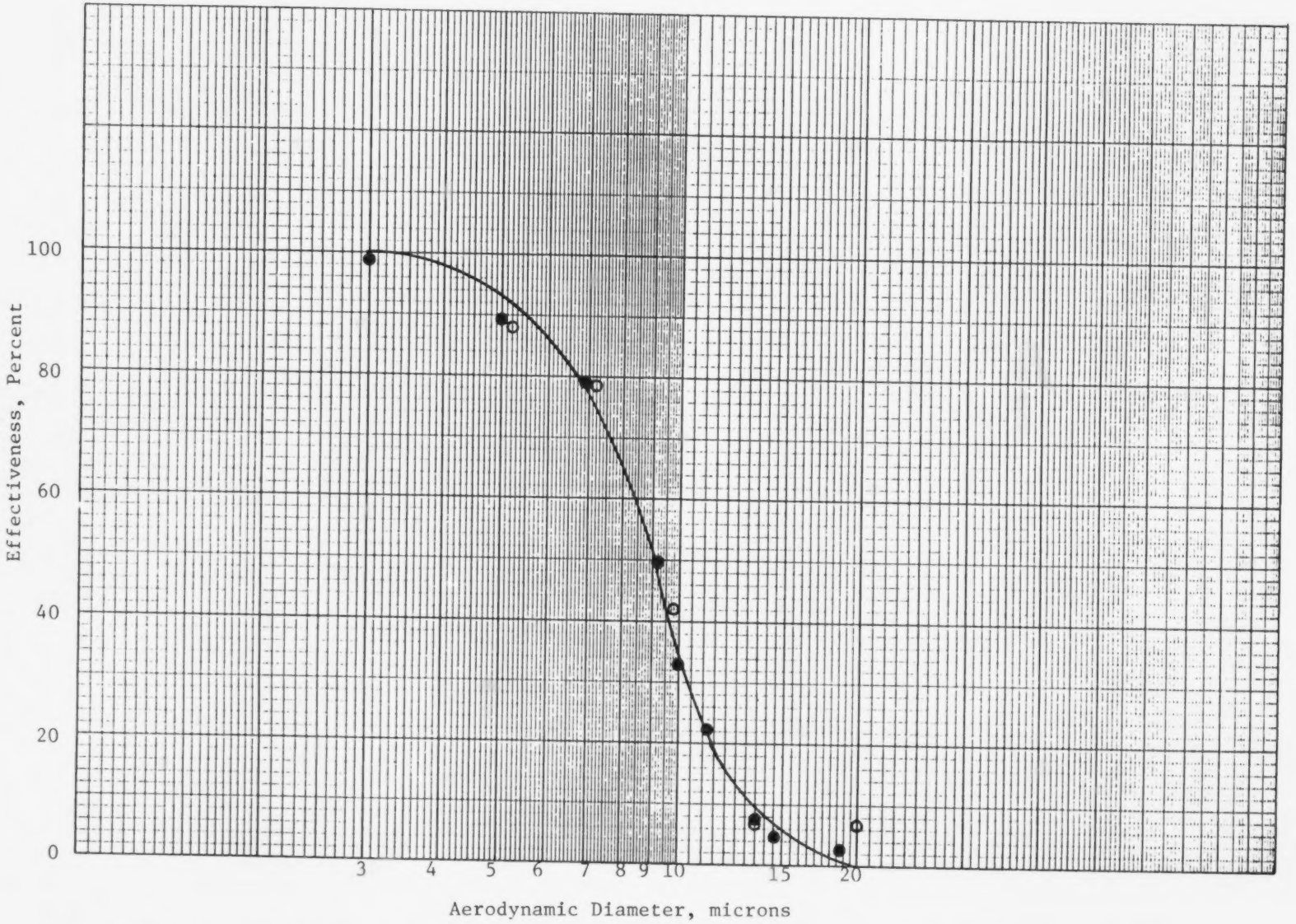


Figure 1. Liquid Particle Effectiveness Curve (●) and Solid Particle Experimental Points (○) for the Wedding IP_{10} Inlet at a Wind Speed of 8 km/hr.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 14

LIQUID AND SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} SIZE SELECTIVE INLET
AT A WINDSPEED OF 8 km/h

TABLE A-1. EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 8 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.0 (L)	104.6, 93.3	99.0	8.1
5.0 (L)	89.1, 91.3, 87.5	89.3	2.1
6.9 (L)	76.4, 81.2, 80.2	79.3	3.2
9.2 (L)	47.5, 51.2, 50.4	49.7	3.9
10.0 (L)	34.0, 32.0, 33.0	33.0	3.0
11.2 (L)	20.8, 22.0, 23.7	22.2	6.6
13.5 (L)	5.6, 10.2, 6.6	7.5	32.4
14.6 (L)	5.2, 4.8, 4.4	4.8	8.3
18.7 (L)	2.8, 3.7, 4.3	3.6	21.0
5.2 (S)	90.4, 91.0, 82.7	88.0	5.3
7.2 (S)	70.9, 85.9, 78.9	78.6	9.6
9.8 (S)	44.5, 42.0, 39.4	42.0	6.1
13.5 (S)	6.7, 6.5, 6.8	6.7	2.3
20.0 (S)	6.7, 7.1., 5.9	6.6	9.3

(L) = Liquid.
(S) = Solid.

4.2 EPA WIND TUNNEL TEST REPORT NO. 15: AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN MODEL 321A SIZE SELECTIVE INLETS AT A WINDSPEED OF 8 km/h: LIQUID PARTICLES

ABSTRACT

Sequential liquid particle tests were performed at a windspeed of 8 km/h on the Wedding IP_{10} and the Andersen Samplers Model 321A size selective inlets at the EPA wind tunnel test facility. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with liquid aerosol particles composed of oleic acid tagged with a uranine tracer covering the size range from 3 to 20 μm aerodynamic diameter. Based on the results of these tests, both inlets meet the proposed specifications for 50-percent cutpoint and sampling effectiveness for liquid particles.

AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN SAMPLERS MODEL 321A SIZE SELECTIVE INLETS

INTRODUCTION

Wind tunnel tests of candidate PM_{10} inlets represent part of the required evaluation of samplers for use in monitoring PM_{10} concentrations in the atmosphere. The present liquid particle study at a windspeed of 8 km/h represents one part of the wind tunnel evaluation. The Wedding IP_{10} and Andersen Samplers Model 321A size selective inlets for the high-volume sampler were tested sequentially using liquid aerosol particles composed of oleic acid tagged with uranine. This report describes the test procedures, results, and conclusions as to the acceptability of these inlets regarding liquid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Liquid oleic acid particles tagged with uranine were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). Liquid particle diameters were verified microscopically using Nye-Bar treated glass slides and a flattening coefficient determined by Olan-Figueroa et al. (1982).

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40 ft^3/min. Isokinetic measurements were made with a 3.63-in x 3.63-in horizontally mounted inlet backed by a glass fiber filter and operated at the same nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were liquid oleic acid of 3, 5, 7, 9, 10, 11, 13, 15, and 20 μm nominal aerodynamic diameter. The test sequence consisted of first

running the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of the Andersen Model 321A inlet, the isokinetic inlet, and the Wedding IP_{10} inlet. The internal surfaces of the isokinetic inlet were washed with 500 mL of 0.1 N NaOH following each isokinetic run, and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Fluoro-Colorimeter II.

RESULTS

The liquid particle sampling effectiveness values and a summary of run results appear in Tables 1 and 2 for the Andersen 321A and Wedding IP_{10} inlets respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the liquid particle sampling effectiveness curves for both the Wedding and Andersen inlets. A smooth curve has been drawn through the data points. From Figure 1 it is seen that the D_{50} cutpoint for the Andersen inlet is 10.4 μm, and for the Wedding inlet it is 9.2 μm. The slope of the curves, estimated by the parameter $\sigma_g=(D_{16}/D_{84})$, is 1.44 for the Andersen inlet and 1.32 for the Wedding inlet. An integration of the two effectiveness curves against two assumed aerosol size distributions was compared to the corresponding expected masses predicted for an "ideal" sampler and presented in Table 3. The first aerosol size distribution is taken from 49 FR 10461, Table D-3, and the second is from the Phoenix I EPA field intercomparison study. The ratios shown in Table 3 reflect the generally larger effectiveness values of the Andersen Model 321A inlet compared to those of the Wedding IP_{10}, as seen in Figure 1.

Shown in Appendix B are plots of sampling effectiveness versus particle size comparing the results obtained in this study to the results obtained by Andersen Samplers and Wedding and Assoc., Inc., for their respective samplers. The manufacturer's results for the Andersen Model 321A inlet were taken from the series 321A Instruction Manual and represent an average over data taken at 2, 8, and 24 km/h. The results for the Wedding IP_{10} were taken from the report "Wind Tunnel Performance Tests" (1984) provided by Wedding and Associates, Inc.

TABLE 1. SUMMARY OF RESULTS FOR THE ANDERSEN MODEL 321A INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.1	101.8	5.6	1.36	0.93	4.7
5.0	92.1	1.7	1.02	1.04	4.4
7.0	88.7	5.6	1.11	1.04	2.1
8.9	70.7	4.0	1.07	1.04	4.0
10.5	47.0	6.0	1.03	1.03	5.2
10.6	44.8	0.9	0.98	1.04	5.5
13.4	27.2	9.9	1.03	0.97	5.1
15.4	15.0	3.8	1.07	0.98	4.7
19.7	5.1	30.8	1.06	1.00	5.2

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 2. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.1	107.0	3.7	1.36	0.93	4.7
5.0	97.0	2.1	1.02	1.04	4.4
7.0	85.8	4.5	1.11	1.04	2.1
8.9	56.4	2.9	1.07	1.04	4.0
10.5	30.2	3.5	1.03	1.03	5.2
10.6	25.8	3.9	0.98	1.04	5.5
13.4	14.4	16.6	1.03	0.97	5.1
15.4	7.4	5.4	1.07	0.98	4.7
19.7	4.7	38.5	1.06	1.00	5.2

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

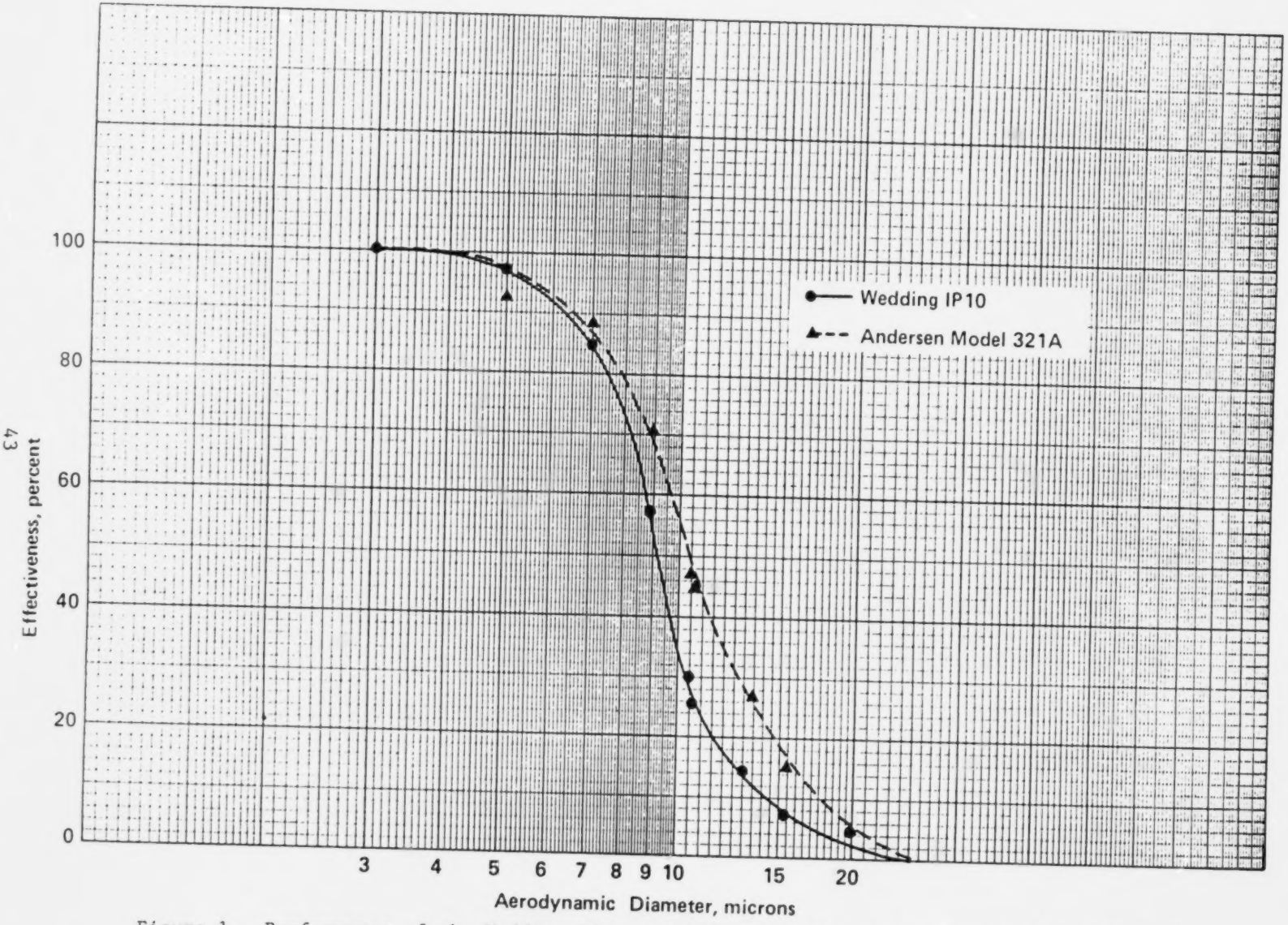


Figure 1. Performance of the Wedding IP_{10} and Andersen Samplers Model 321A Size Selective Inlets at 8 km/hr.

TABLE 3. RATIO OF TEST SAMPLER MASS CONCENTRATION COMPARED TO THE IDEAL SAMPLER FOR TWO AEROSOL SIZE DISTRIBUTIONS

Sampler	Expected mass concentration ($\mu g/m^3$)	Ratio
Ideal Sampler[a]	52.3	--
Wedding IP_{10}	51.5	0.985
Andersen 321A	53.4	1.021
Ideal Sampler[b]	106.5	--
Wedding IP_{10}	105.8	0.993
Andersen 321A	115.5	1.085

[a]Aerosol size distribution from 49 FR 10461, Table D-3.

[b]Aerosol size distribution from Phoenix I, EPA field intercomparison study.

CONCLUSIONS

Table 4 summarizes the performance specifications for acceptable PM_{10} inlets, manufacturer's results, and the results of this study. Based on this study, both the Andersen Samplers Model 321A and the Wedding IP_{10} size selective inlets meet the specifications for cutpoint and liquid particle sampling effectiveness.

TABLE 4. PERFORMANCE OF THE TEST INLETS COMPARED TO PERFORMANCE SPECIFICATIONS IN 40 CFR PART 53

Performance parameter	Specification	Manufacturer's results	Results from this study
Sampling effectiveness of liquid particles	± 10% mass concentration predicted by ideal sampler		
Wedding IP_{10}		-1.5%	-1.5%
Andersen 321A		-0.004%	+2.1%
50% cutpoint	10 ± 1 μm		
Wedding IP_{10}		9.9 μm	9.2 μm
Andersen 321A		9.8 μm	10.4 μm

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 15

SAMPLING EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} AND THE ANDERSEN MODEL 321A SIZE SELECTIVE INLETS

TABLE A-1. SAMPLING EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 8 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.1	111.0, 107.1, 103	107.0	3.7
5.0	96.0, 99.3, 95.7	97.0	2.1
7.0	86.4, 89.3, 81.7	85.8	4.5
8.9	57.5, 57.2, 54.5	56.4	2.9
10.5	30.7, 29.0, 30.9	30.2	3.5
10.6	26.9, 25.7, 24.9	25.8	3.9
13.4	14.5, 16.8, 12.0	14.4	16.6
15.4	7.5, 7.0, 7.8	7.4	5.4
19.7	6.6, 4.5, 3.0	4.7	38.5

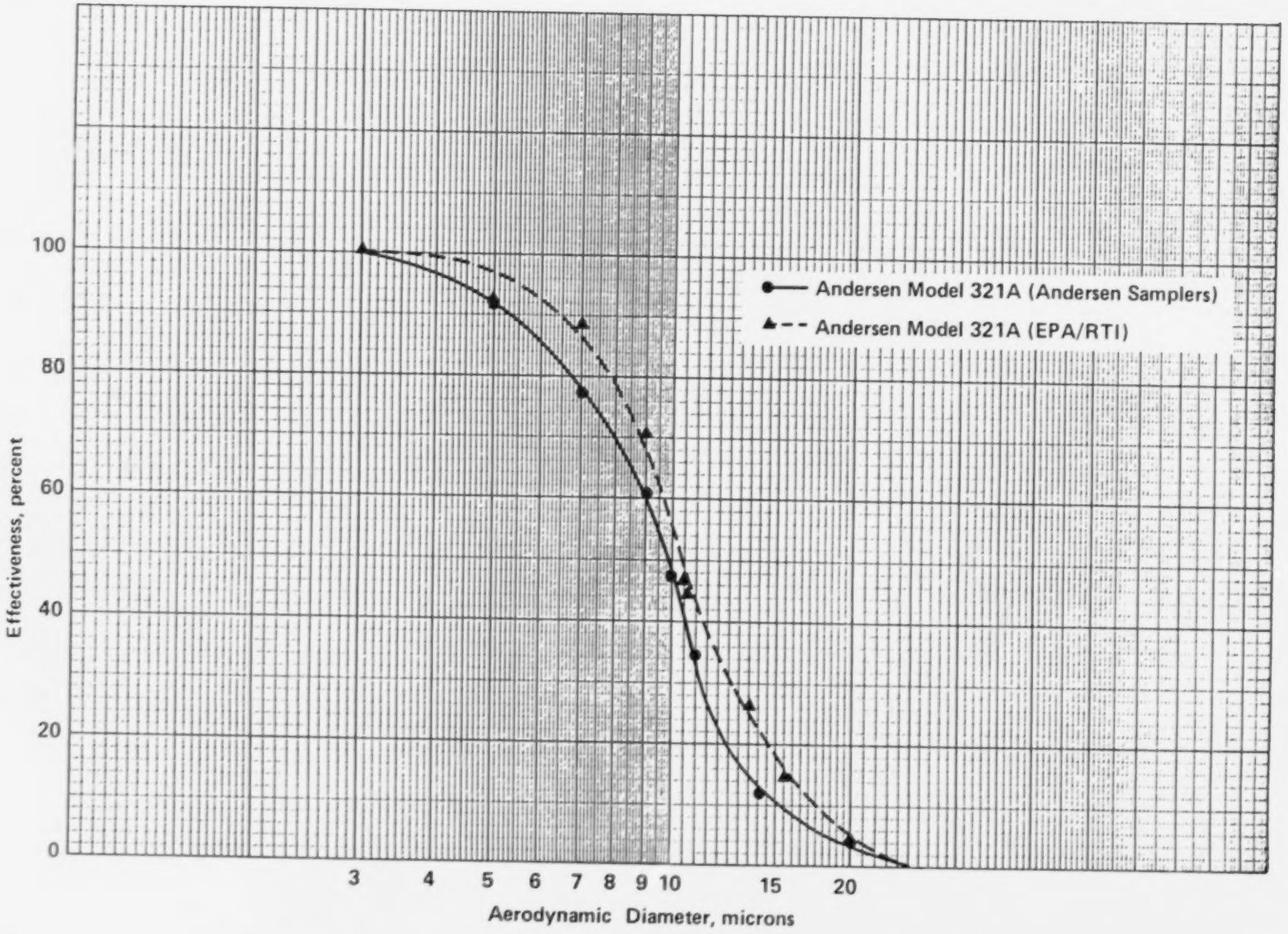
TABLE A-2. SAMPLING EFFECTIVENESS VALUES FOR THE ANDERSEN SAMPLERS MODEL 321A INLET AT 8 km/h

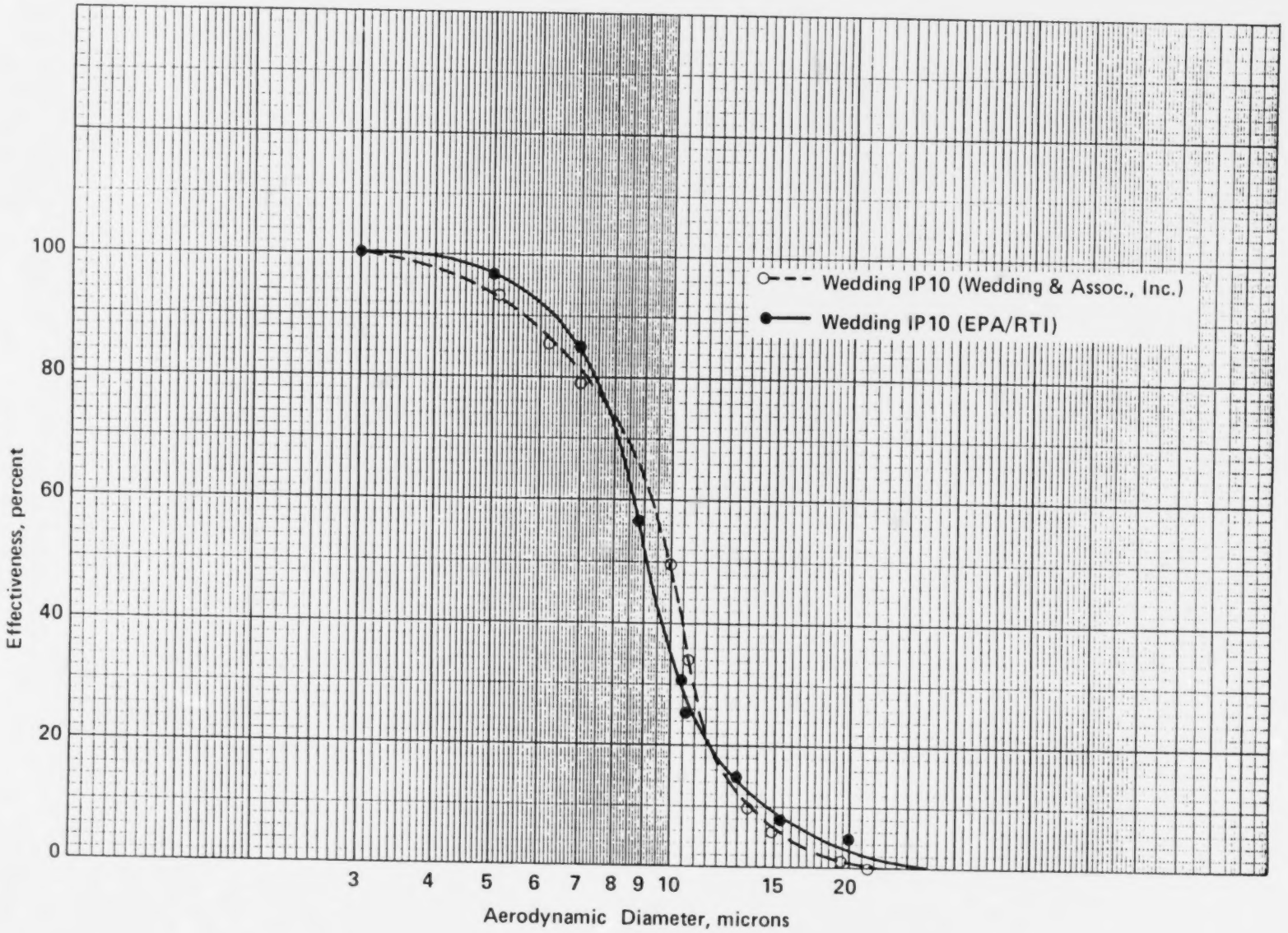
Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.1	97.6, 99.5, 108.3	101.8	5.6
5.0	90.5, 92.2, 93.7	92.1	1.7
7.0	93.2, 89.6, 83.3	88.7	5.6
8.9	69.0, 73.9, 69.1	70.7	4.0
10.5	44.9, 45.8, 50.2	47.0	6.0
10.6	45.3, 44.5, 44.7	44.8	0.9
13.4	25.7, 25.6, 30.3	27.2	9.9
15.4	15.7, 14.7, 14.7	15.0	3.0
19.7	6.8, 4.8, 3.7	5.1	30.8

APPENDIX B

FOR EPA WIND TUNNEL TEST REPORT NO. 15

PLOTS COMPARING THE RESULTS OF THIS STUDY WITH THE RESULTS OBTAINED BY ANDERSEN SAMPLERS AND WEDDING AND ASSOC., INC., FOR THEIR RESPECTIVE SAMPLERS


Andersen Model 321A (Andersen Samplers)
Andersen Model 321A (EPA/RTI)
Effectiveness, percent
100
80
60
40
20
0
3
4
5
6
7
8
9
10
15
20
Aerodynamic Diameter, microns


Wedding IP10 (Wedding & Assoc., Inc.)
Wedding IP10 (EPA/RTI)
Effectiveness, percent
100
80
60
40
20
0
3
4
5
6
7
8
9
10
15
20
Aerodynamic Diameter, microns

4.3 EPA WIND TUNNEL TEST REPORT NO. 16: AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN MODEL 321A SIZE SELECTIVE INLETS AT A WINDSPEED OF 8 km/h: SOLID PARTICLES

ABSTRACT

Sequential solid particle tests were performed at a windspeed of 8 km/h on the Wedding IP_{10} and the Andersen Samplers Model 321A size selective inlets at the EPA wind tunnel test facility. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with solid aerosol particles composed of ammonium fluorescein covering the size range from 3 to 20 μm aerodynamic diameter. Based on the results of these tests, both inlets meet the proposed specifications for 50-percent cutpoint and solid particle sampling effectiveness.

AN EVALUATION OF WEDDING IP_{10} AND ANDERSEN SAMPLERS MODEL 321A SIZE SELECTIVE INLETS

INTRODUCTION

Wind tunnel tests of candidate PM_{10} inlets represent part of the required evaluation of samplers for use in monitoring PM_{10} concentrations in the atmosphere. The present solid particle study at a windspeed of 8 km/h represents one part of the wind tunnel evaluation. The Wedding IP_{10} and Andersen Samplers Model 321A size selective inlets for the high-volume sampler were tested sequentially using solid ammonium fluorescein aerosol particles. This report describes the test procedures, results, and conclusions as to the acceptability of these inlets regarding solid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Solid ammonium fluorescein particles were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). The solid particles were collected on untreated glass slides, and their diameters were verified microscopically.

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40 ft^3/min. Isokinetic measurements were made with a 3.63-in x 3.63-in horizontally mounted inlet backed by a glass fiber filter and operated at the same nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were solid ammonium fluorescein of 3, 5, 7, 9, 10, 11, 13, 15, and 20 μm nominal aerodynamic diameter. The test sequence consisted of

first running the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of the Andersen Model 321A inlet, the isokinetic inlet, and the Wedding IP_{10} inlet. The internal surfaces of the isokinetic inlet were washed with 0.1 N NH_4OH following each isokinetic run, and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Fluoro-Colorimeter II.

RESULTS

The solid particle sampling effectiveness values and a summary of run results appear in Tables 1 and 2 for the Andersen 321A and Wedding IP_{10} inlets, respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the solid particle sampling effectiveness curves for both the Wedding and Andersen inlets. A smooth curve has been drawn through the data points. Figure 2 shows the liquid particle curves (obtained previously, see Report #15) along with the solid particle experimental points for a windspeed of 8 km/h. From Figure 1 it is seen that the D_{50} cutpoint for the Andersen inlet is 10.6 μm, and for the Wedding inlet is 9.3 μm. The slope of the curves, estimated by the parameter $\sigma_g=(D_{16}/D_{84})$, is 1.48 for the Andersen inlet and 1.37 for the Wedding inlet. An integration of the two effectiveness curves was performed against an assumed aerosol size distribution and compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D3.) The results of this comparison are presented in Table 3 along with a comparison of liquid vs. solid particle results for the D_{50} cutpoint, σ_g, and the 20-μm effectiveness values.

CONCLUSIONS

Based on this study, both the Andersen Samplers Model 321A and the Wedding IP_{10} size selective inlets meet the specifications for 50-percent cutpoint and solid particle sampling effectiveness.

TABLE 1. SUMMARY OF RESULTS FOR THE ANDERSEN MODEL 321A INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.0	98.3	3.2	1.24	1.10	3.2
5.0	90.5	3.3	0.96	1.07	2.7
7.1	82.6	4.1	1.04	1.07	4.1
9.2	68.0	0.8	1.13	1.00	4.6
10.2	60.4	8.3	1.17	1.01	3.5
11.3	43.2	7.3	1.06	0.99	3.0
13.1	23.8	4.4	1.10	1.02	4.6
15.1	16.2	7.7	1.08	1.02	4.1
20.0	4.8	17.4	1.09	1.09	2.8

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 2. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.0	103.7	8.6	1.24	1.10	3.2
5.0	96.6	7.2	0.96	1.07	2.7
7.1	81.4	4.1	1.04	1.07	4.1
9.2	52.9	1.7	1.13	1.00	4.6
10.2	41.1	8.1	1.17	1.01	3.5
11.3	25.9	6.0	1.06	0.99	3.0
13.1	12.6	9.2	1.10	1.02	4.6
15.1	8.1	1.9	1.08	1.02	4.1
20.0	7.4	1.6	1.09	1.09	2.8

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

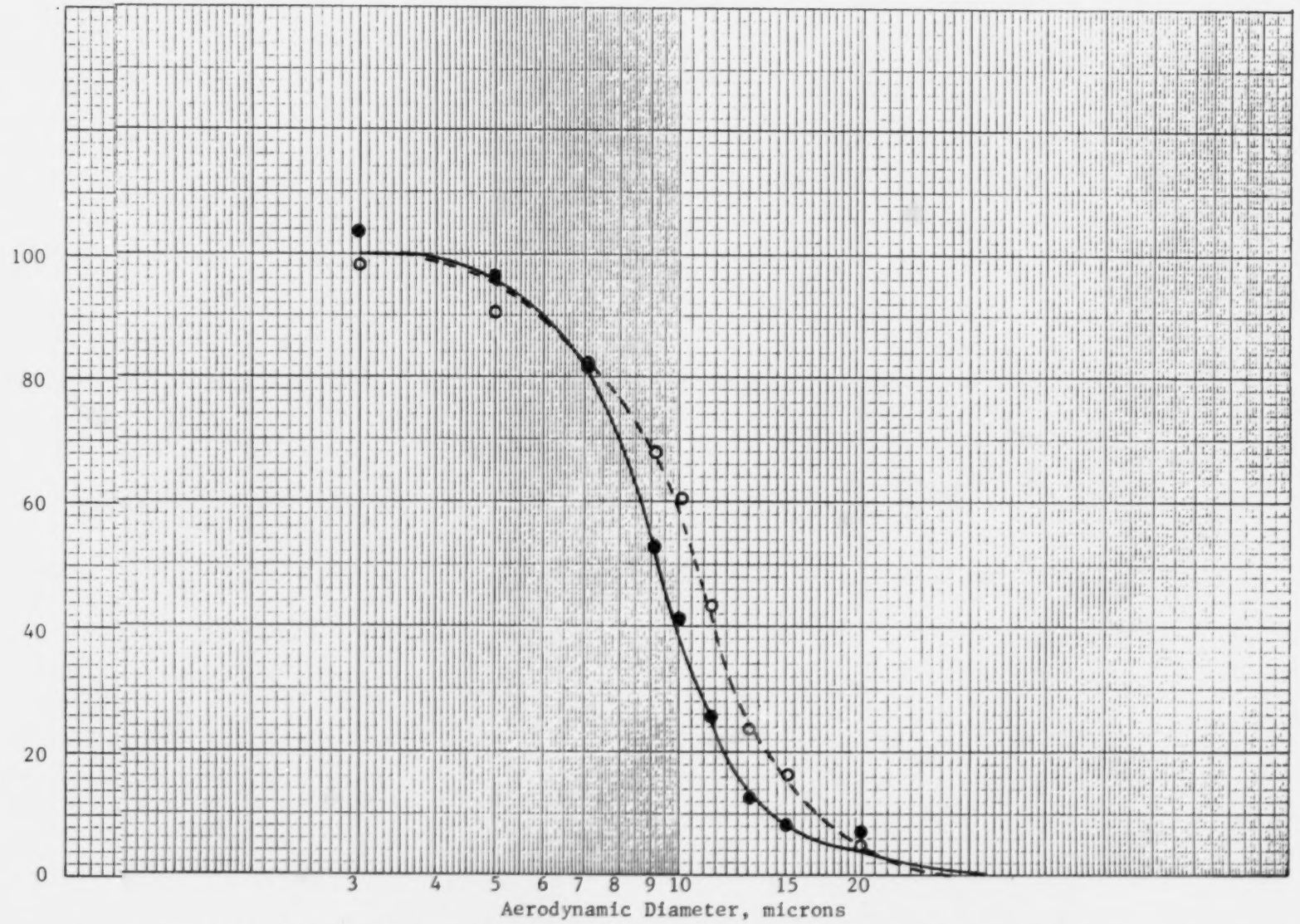


Figure 1. Solid Particle Sampling Effectiveness Curves for the Wedding IP_{10} (●) and Andersen Model 321A (○) Inlets at 8 km/hr.

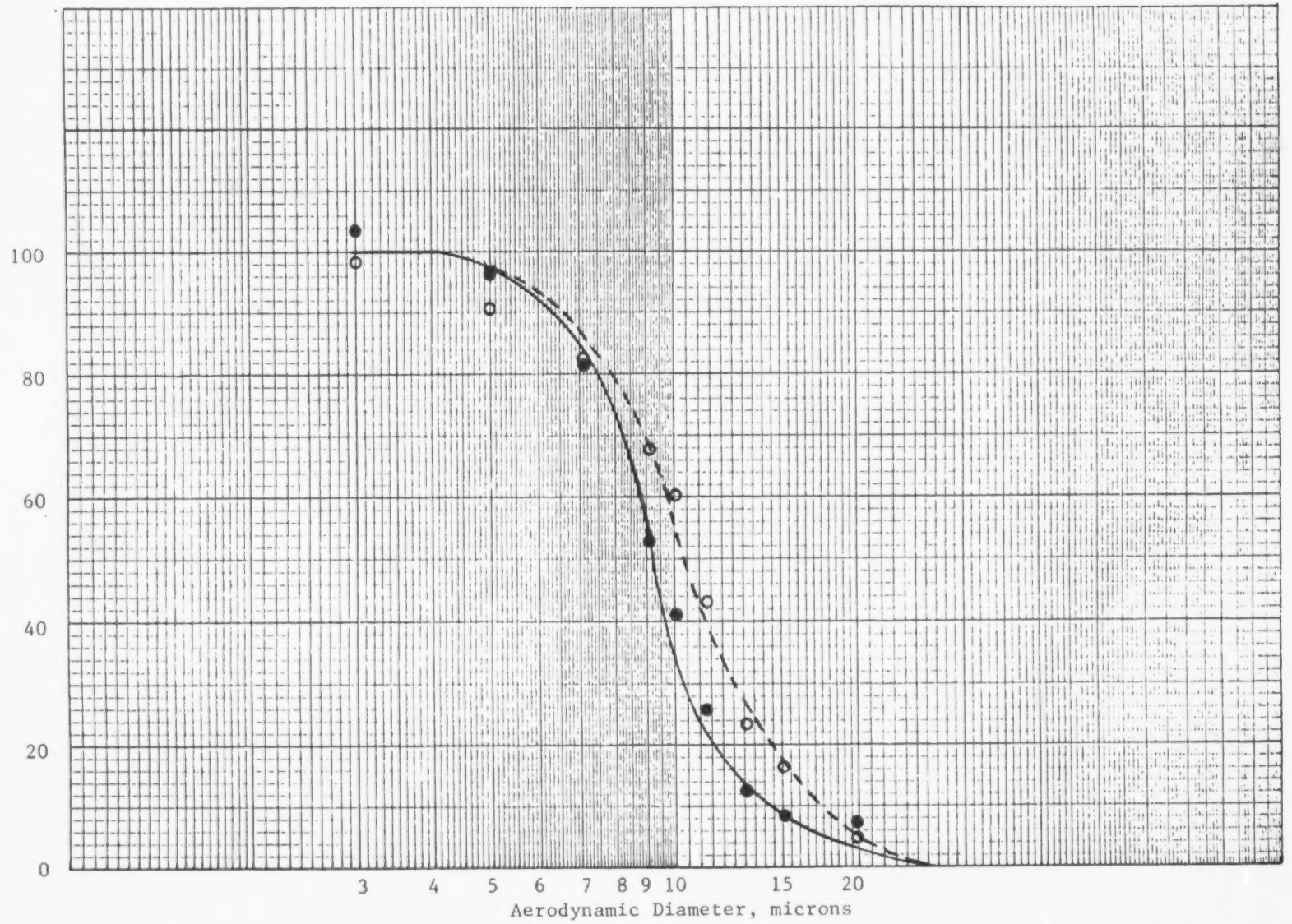


Figure 2. Liquid Particle Sampling Effectiveness Curves and Solid Particle Experimental Points for the Wedding IP_{10} (●) and Andersen Model 321A (0) Inlets at 8 km/hr.

TABLE 3. COMPARISON OF SOLID AND LIQUID PARTICLE RESULTS FOR THE WEDDING IP_{10} AND ANDERSEN 321A INLETS AT A WINDSPEED OF 8 km/h

Parameter	IP_{10}		321A	
	Liquid	Solid	Liquid	Solid
Mass ratio[a]	0.985	0.990	1.021	1.025
50% cutpoint	9.2	9.3	10.4	10.6
σ_g	1.32	1.37	1.44	1.48
20-μm effectiveness	4.7	7.4	5.1	4.8

[a]This ratio is the mass collected by the test inlet (from integrating the effectiveness curve against an assumed aerosol size distribution) compared to the mass predicted for an "ideal" sampler using the aerosol size distribution 49 FR 10461, Table D-3.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 16

SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} AND THE ANDERSEN MODEL 321A SIZE SELECTIVE INLETS
AT A WINDSPEED OF 8 km/h

TABLE A-1. SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 8 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.0	106.5, 110.9, 93.8	103.7	8.6
5.0	99.5, 101.6, 88.7	96.6	7.2
7.1	77.6, 83.6, 83.1	81.4	4.1
9.2	52.2, 53.9, 52.6	52.9	1.7
10.2	37.3, 42.4, 43.6	41.1	8.1
11.3	24.4, 27.5, 25.9	25.9	6.0
13.1	13.5, 13.0, 11.3	12.6	9.2
15.1	8.3, 8.0, 8.1	8.1	1.9
20.0	7.3, 7.3, 7.5	7.4	1.6

TABLE A-2. SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES FOR THE ANDERSEN SAMPLERS MODEL 321A INLET AT A WINDSPEED OF 8 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.0	98.9, 101.2, 94.9	98.3	3.2
5.0	91.8, 87.0, 92.6	90.5	3.3
7.1	78.7, 84.4, 84.8	82.6	4.1
9.2	67.5, 68.6, 68.0	68.0	0.8
10.2	64.6, 54.8, 61.7	60.4	8.3
11.3	40.1, 43.1, 46.4	43.2	7.3
13.1	23.7, 22.8, 24.9	23.8	4.4
15.1	15.0, 16.1, 17.5	16.2	7.7
20.0	5.8, 4.3, 4.4	4.8	17.4

4.4 EPA WIND TUNNEL TEST REPORT NO. 17: AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN MODEL 321A SIZE SELECTIVE INLETS AT A WINDSPEED OF 2 km/h: LIQUID PARTICLES

ABSTRACT

Sequential liquid particle tests were performed at a windspeed of 2 km/h on the Wedding IP_{10} and the Andersen Samplers Model 321A size selective inlets at the EPA wind tunnel test facility. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with liquid aerosol particles composed of oleic acid tagged with a uranine tracer covering the size range from 7 to 13 μm aerodynamic diameter. Based on the results of these tests, both inlets meet the proposed specifications for 50-percent cutpoint and liquid particle sampling effectiveness. (The effectiveness curves have been extrapolated for particle sizes less than 7 and greater than 13 μm in order to perform the expected mass calculations.)

AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN SAMPLERS MODEL 321A SIZE SELECTIVE INLETS

INTRODUCTION

Wind tunnel tests of candidate PM_{10} inlets represent part of the required evaluation of samplers for use in monitoring PM_{10} concentrations in the atmosphere. The present liquid particle study at a windspeed of 2 km/h represents one part of the wind tunnel evaluation. The Wedding IP_{10} and Andersen Samplers Model 321A size selective inlets for the high-volume sampler were tested sequentially using liquid aerosol particles composed of oleic acid tagged with uranine. This report describes the test procedures, results, and conclusions as to the acceptability of these inlets regarding liquid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Liquid oleic acid particles tagged with uranine were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). Liquid particle diameters were verified microscopically using Nye-Bar treated glass slides and a flattening coefficient determined by Olan-Figueroa et al. (1982).

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40 ft^3/min. Isokinetic measurements were made with a 7.25-in x 7.25-in horizontally mounted inlet backed by a glass fiber filter and operated at the same nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were liquid oleic acid of 7, 9, 10, 11, and 13 μm nominal aerodynamic diameter. The test sequence consisted of first running the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of the Andersen Model 321A inlet, the isokinetic inlet, and the Wedding IP_{10} inlet. The internal surfaces of the isokinetic inlet were washed with 500 mL of 0.1 N NaOH following each isokinetic run, and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Fluoro-Colorimeter II.

RESULTS

The liquid particle sampling effectiveness values and a summary of run results appear in Tables 1 and 2 for the Andersen 321A and Wedding IP_{10} inlets, respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the liquid particle sampling effectiveness curves for both the Wedding and Andersen inlets. A smooth curve has been drawn through the data points and extrapolated (shown by the dotted lines) at the small ($<7\mu$) and large ($>13\mu$) particle sizes. From Figure 1 it is seen that the D_{50} cutpoint for the Andersen inlet is 10.5 μm and for the Wedding inlet it is 9.35 μm. The slope of the curves, estimated by the parameter $\sigma_g = (D_{16}/D_{84})^{1/2}$, is 1.39 for the Andersen inlet and 1.28 for the Wedding inlet. An integration of the two effectiveness curves was performed against an assumed aerosol size distribution and compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D-3.) The results of this comparison are presented in Table 3 along with a comparison of liquid particle results at 2 and 8 km/h for the D_{50} cutpoint and σ_g.

CONCLUSIONS

Based on this study, both the Andersen Samplers Model 321A and the Wedding IP_{10} size selective inlets meet the specifications for 50-percent cutpoint and liquid particle sampling effectiveness.

TABLE 1. SUMMARY OF RESULTS FOR THE ANDERSEN MODEL 321A INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter [a]	Microscope size/ generator size [b]	Uniformity CV (%)[c]
6.6	92.7	2.6	1.18	1.01	1.8
8.6	72.5	2.8	1.07	1.02	4.9
9.6	62.3	0.6	1.10	0.99	4.0
10.3	53.0	1.7	1.08	1.02	4.0
12.6	30.4	0.7	1.08	1.01	3.9

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 2. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter [a]	Microscope size/ generator size [b]	Unformity CV (%)[c]
6.6	94.5	1.2	1.18	1.01	1.8
8.6	63.7	1.4	1.07	1.02	4.9
9.6	46.7	1.6	1.10	0.99	4.0
10.3	35.5	4.2	1.08	1.02	4.0
12.6	12.4	4.3	1.08	1.01	3.9

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

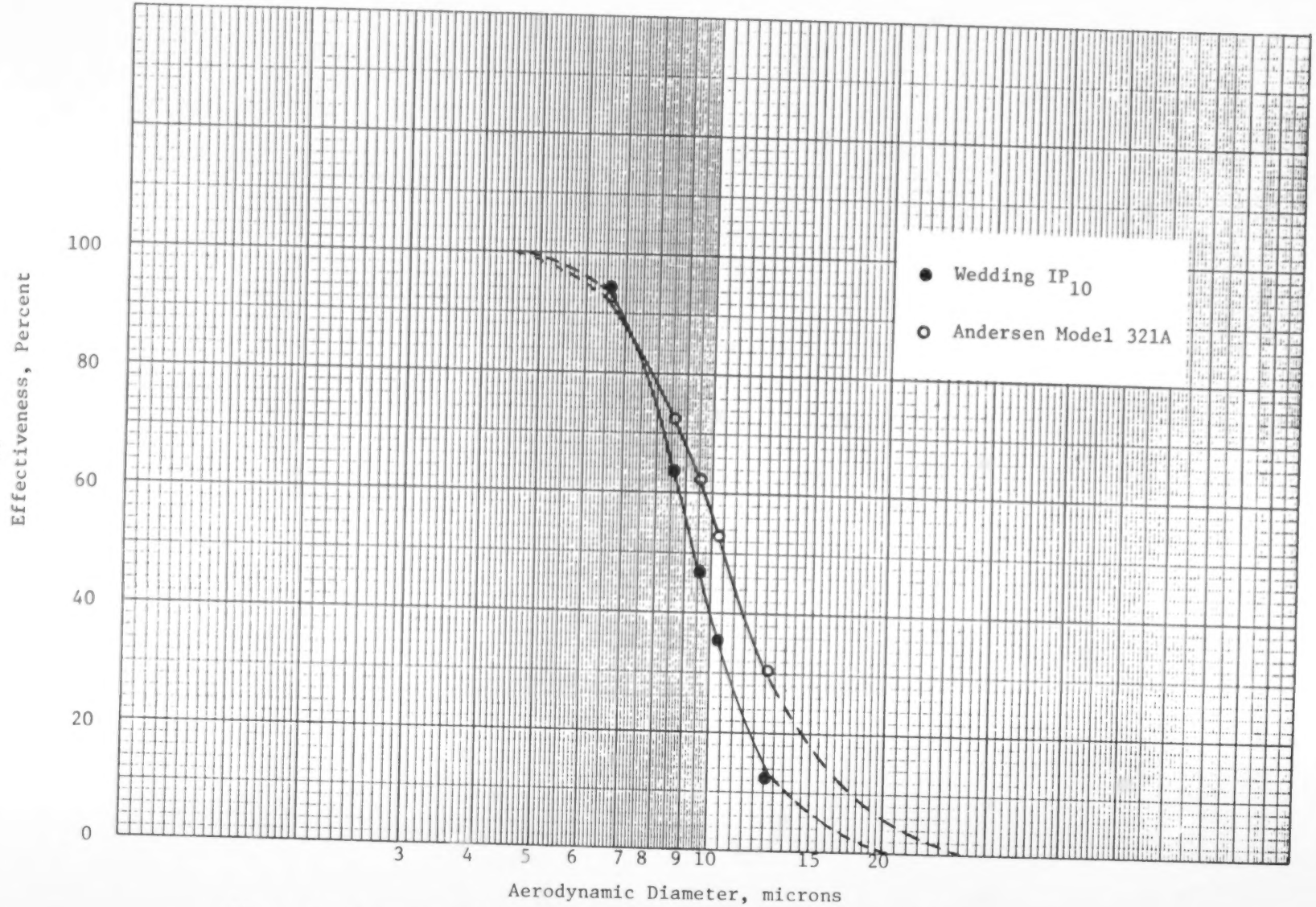


Figure 1. Liquid Particle Effectiveness Curves for the Wedding IP_{10} and Andersen Model 321A Inlets at 2 km/hr. (Dotted lines represent an extrapolation of the data.)

TABLE 3. COMPARISON OF LIQUID PARTICLE RESULTS AT 2 AND 8 km/h FOR THE WEDDING IP_{10} AND ANDERSEN 321A INLETS

Parameter	IP_{10}		321A	
	2 km/h	8 km/h	2 km/h	8 km/h
Mass ratio[a]	0.989	0.985	1.030	1.021
50% cutpoint	9.35	9.2	10.5	10.4
σ_g	1.30	1.32	1.45	1.44

[a]This ratio is the mass collected by the test inlet (from integrating the effectiveness curve against an assumed aerosol size distribution) compared to the mass predicted for an "ideal" sampler using the aerosol size distribution in 49 FR 10461, Table D-3.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 17

LIQUID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} AND THE ANDERSEN MODEL 321A
SIZE SELECTIVE INLETS AT A WINDSPEED OF 2 km/h

TABLE A-1. SAMPLING EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
6.6	94.5, 95.7, 93.4	94.5	1.2
8.6	63.2, 63.2, 64.8	63.7	1.4
9.6	47.5, 46.5, 46.0	46.7	1.6
10.3	33.8, 36.2, 36.5	35.5	4.2
12.6	11.8, 12.6, 12.8	12.4	4.3

TABLE A-2. SAMPLING EFFECTIVENESS VALUES FOR THE ANDERSON MODEL 321A INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
6.6	95.5, 91.5, 91.2	92.7	2.6
8.6	73.4, 70.1, 73.9	72.5	2.8
9.6	61.9, 62.7, 62.4	62.3	0.6
10.3	53.8, 52.0, 53.1	53.0	1.7
12.6	30.3, 30.6, 30.2	30.4	0.7

4.5 EPA WIND TUNNEL TEST REPORT NO. 18: AN EVALUATION OF THE WEDDING IP_{10} AND ANDERSEN MODEL 321A SIZE SELECTIVE INLETS AT A WINDSPEED OF 2 km/h: SOLID PARTICLES

ABSTRACT

Sequential solid particle tests were performed at a windspeed of 2 km/h on the Wedding IP_{10} and the Andersen Samplers Model 321A size selective inlets at the EPA wind tunnel test facility. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with solid aerosol particles composed of ammonium fluorescein covering the size range from 7 to 13 μm aerodynamic diameter. Based on the results of these tests, both inlets meet the proposed specifications for 50-percent cutpoint and solid particle sampling effectiveness. (The effectiveness curves have been extrapolated for particle sizes less than 7 and greater than 13 μm in order to perform the expected mass calculations.)

AN EVALUATION OF THE WEDDING IP_{10} ANDERSEN SAMPLERS MODEL 321A SIZE SELECTIVE INLETS

INTRODUCTION

Wind tunnel tests of candidate PM_{10} inlets represent part of the required evaluation of samplers for use in monitoring PM_{10} concentrations in the atmosphere. The present solid particle study at a windspeed of 2 km/h represents one part of the wind tunnel evaluation. The Wedding IP_{10} and Andersen Samplers Model 321A size selective inlets for the high-volume sampler were tested sequentially using solid ammonium fluorescein aerosol particles. This report describes the test procedures, results, and conclusions as to the acceptability of these inlets regarding solid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Solid ammonium fluorescein particles were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). The solid particles were collected on untreated glass slides, and their diameters were verified microscopically.

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40 ft^3/min. Isokinetic measurements were made with a 7.25-in x 7.25-in horizontally mounted inlet backed by a glass fiber filter and operated at the same nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were solid ammonium fluorescein of 7, 9, 10, 11, and 13 μm nominal aerodynamic diameter. The test sequence consisted of first running

the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of the Andersen Model 321A inlet, the isokinetic inlet, and the Wedding IP_{10} inlet. The internal surfaces of the isokinetic inlet were washed with 500 mL of 0.1 N NH_4OH following each isokinetic run, and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Fluoro-Colorimeter II.

RESULTS

The solid particle sampling effectiveness values and a summary of run results appear in Tables 1 and 2 for the Andersen 321A and Wedding IP_{10} inlet, respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the solid particle sampling effectiveness curves for both the Wedding and Andersen inlets. Figure 2 shows the liquid particle curves (obtained previously, see Report #17) along with the solid particle experimental points for a windspeed of 2 km/h. From Figure 1 it is seen that the D_{50} cutpoint for the Andersen inlet is 10.2 μm and for the Wedding inlet it is 9.35 μm. The slope of the curves, estimated by the parameter $\sigma_g = (D_{16}/D_{84})^{1/2}$, is 1.40 for the Andersen inlet and 1.28 for the Wedding inlet. An integration of the two curves was performed against an assumed aerosol size distribution and compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D3.) The results of this comparison are presented in Table 3 along with a comparison of liquid vs. solid particle results for the D_{50} cutpoint, σ_g, and the 20-μm effectiveness values.

CONCLUSIONS

Based on this study, both the Andersen Samplers Model 321A and the Wedding IP_{10} size selective inlets meet the specifications for 50-percent cutpoint and solid particle sampling effectiveness.

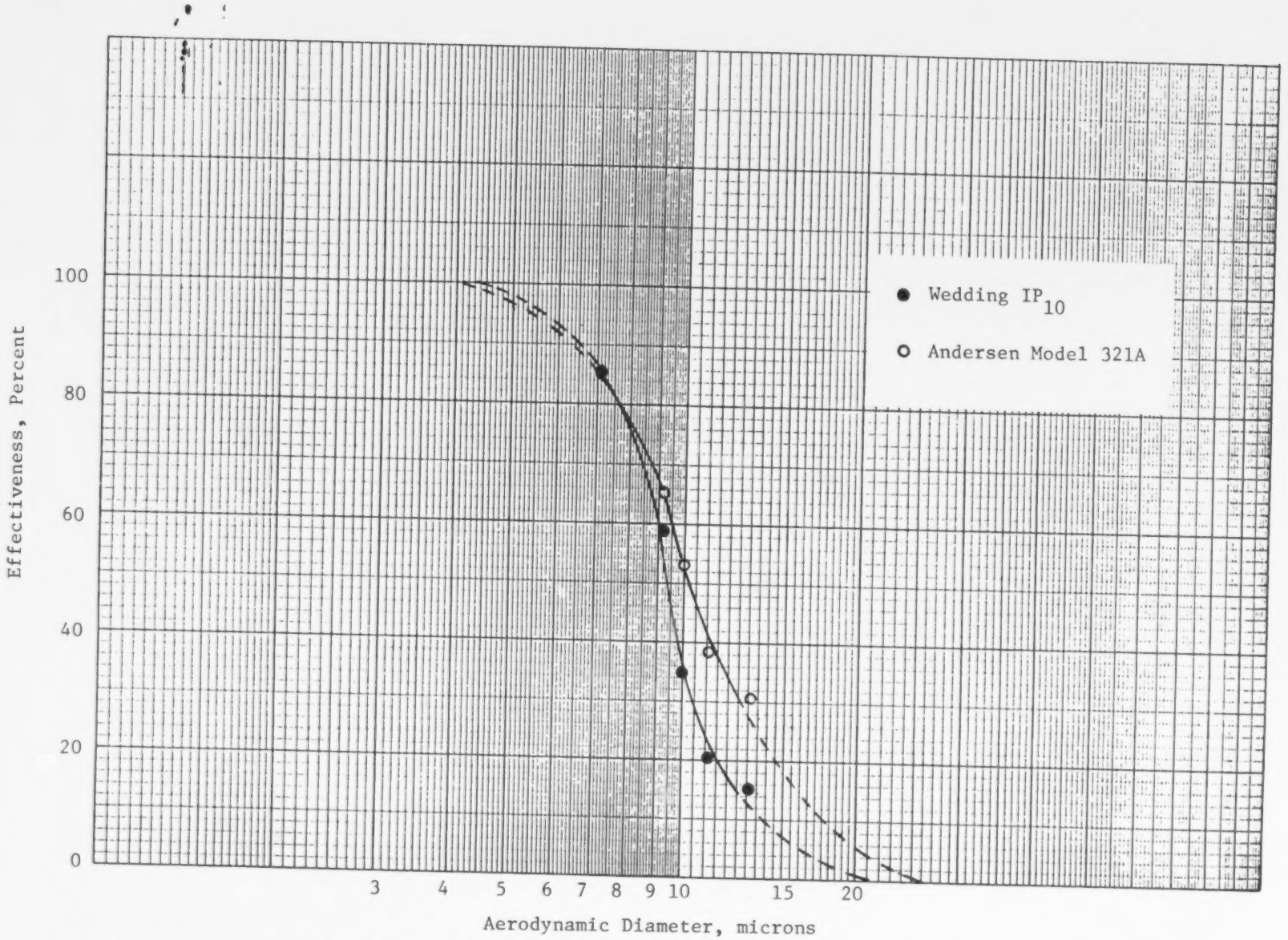


Figure 1. Solid Particle Effectiveness Curves for the Wedding IP_{10} and Andersen Model 321A Inlets at 2 km/hr.

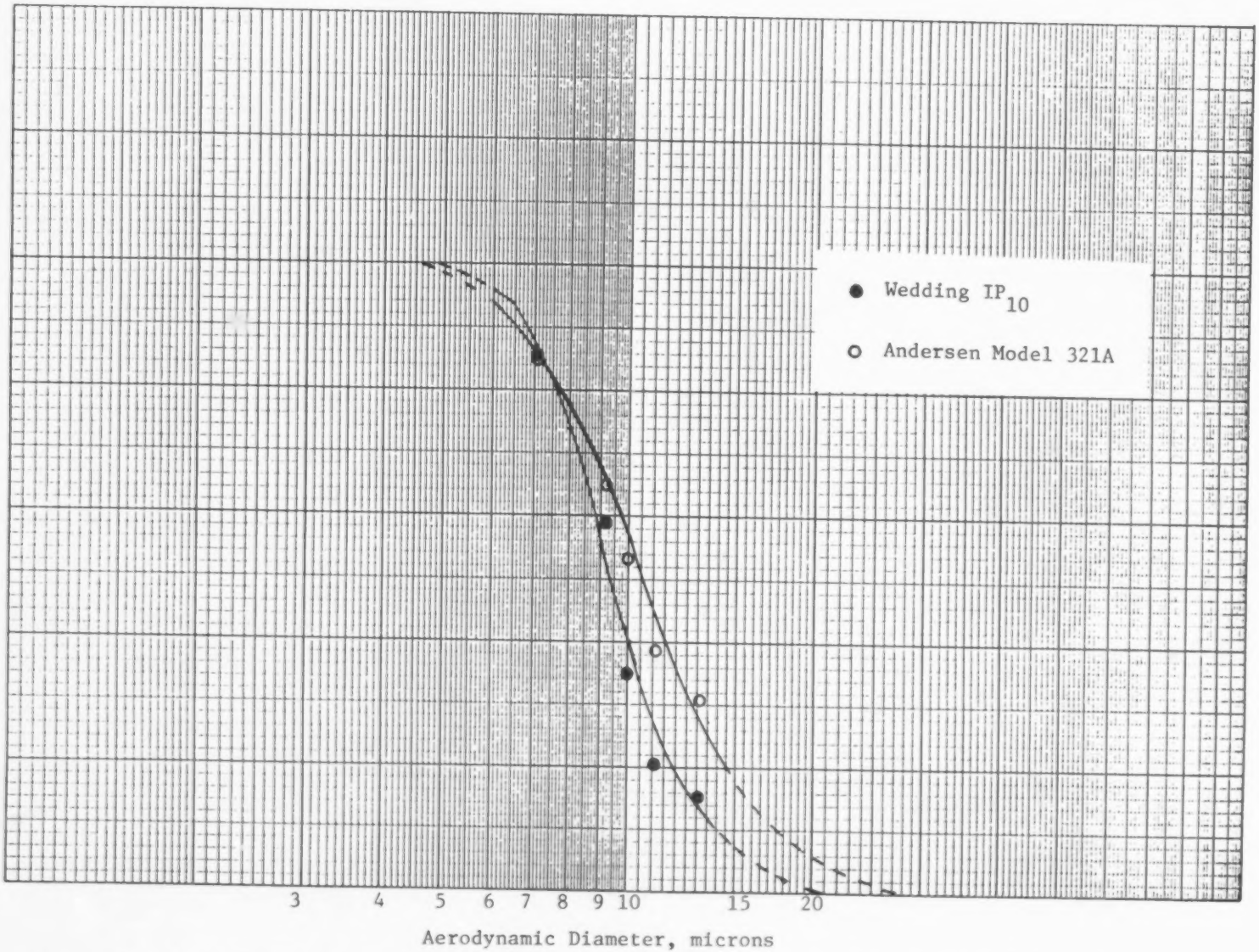


Figure 2. Liquid Particle Effectiveness Curves and Solid Particle Experimental Points for the Wedding IP_{10} and Andersen 321A Inlets at 2 km/hr.

TABLE 1. SUMMARY OF RESULTS FOR THE ANDERSEN MODEL 321A INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter [a]	Microscope size/ generator size [b]	Uniformity CV (%)[c]
7.1	85.1	5.1	1.13	1.01	5.4
9.2	65.4	1.7	1.24	1.03	5.5
10.0	53.3	3.8	1.05	1.04	4.4
11.1	38.3	8.5	1.09	1.01	4.7
13.1	30.7	7.4	0.81[d]	1.04	3.6

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

[d]The O-rings that form the seal between the rake sampling nozzle and corresponding filter were not properly positioned, causing the rake to give low concentration readings.

TABLE 2. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
7.1	85.7	0.7	1.13	1.01	5.4
9.2	59.0	2.9	1.24	1.03	5.5
10.0	34.9	4.7	1.05	1.04	4.4
11.1	20.4	11.0	1.09	1.01	4.7
13.1	15.5	9.7	0.81[d]	1.04	3.6

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

[d]The O-rings that form the seal between the rake sampling nozzle and corresponding filter were not properly positioned, causing the rake to give low concentration readings.

TABLE 3. COMPARISON OF SOLID AND LIQUID PARTICLE RESULTS FOR THE WEDDING IP_{10} AND ANDERSEN 321A INLETS AT A WINDSPEED OF 2 km/h

	IP_{10}		321A	
Parameter	Liquid	Solid	Liquid	Solid
Mass ratio[a]	0.989	0.987	1.030	1.026
50% cutpoint	9.35	9.35	10.5	10.2
σ_g	1.30	1.31	1.45	1.47
20 μm effectiveness (from curve)	0.5	0.5	4.5	5.5

[a]This ratio is the mass collected by the test inlet (from integrating the effectiveness curve against an assumed aerosol size distribution) compared to the mass predicted for an "ideal" sampler using the aerosol size distribution in 49 FR 10461, Table D-3.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 18

SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} AND THE ANDERSEN MODEL 321A
SIZE SELECTIVE INLETS AT A WINDSPEED OF 2 km/h

TABLE A-1. SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
7.1	86.2, 85.0, 85.9	85.7	0.7
9.2	58.6, 57.5, 60.9	59.0	2.9
10.0	33.1, 36.3, 35.4	34.9	4.7
11.1	18.6, 22.9, 19.6	20.4	11.0
13.1	13.9, 16.9, 15.7	15.5	9.7

TABLE A-2. SOLID PARTICLE SAMPLING EFFECTIVENESS VALUES FOR THE ANDERSEN SAMPLERS MODEL 321A INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV (percent)
7.1	90.1, 82.7, 82.6	85.1	5.1
9.2	64.7, 66.7, 64.9	65.4	1.7
10.0	53.8, 55.1, 51.1	53.3	3.8
11.1	34.5, 40.2, 40.1	38.3	8.5
13.1	33.3, 29.4, 29.3	30.7	7.4

4.6 EPA WIND TUNNEL TEST REPORT NO. 19: AN EVALUATION OF A "CLEAN" AND A "DIRTY" FIELD-TESTED WEDDING IP_{10} SIZE SELECTIVE INLET AT A WINDSPEED OF 2 km/h: LIQUID PARTICLES

ABSTRACT

Sequential liquid particle tests were performed at a windspeed of 2 km/h on a clean Wedding IP_{10} and a dirty field-tested Wedding IP_{10} size selective inlet at the EPA wind tunnel test facility. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with liquid aerosol particles composed of oleic acid tagged with a uranine tracer covering the size range from 3 to 13 μm aerodynamic diameter. Based on the results of these tests, both inlets meet the proposed specification for liquid particle sampling effectiveness. However, the field-tested inlet does not meet the proposed specification for 50-percent cutpoint. (The effectiveness curves have been extrapolated for particle sizes greater than 13 μm in order to perform the expected mass calculations.)

AN EVALUATION OF A "CLEAN" AND A "DIRTY" FIELD TESTED WEDDING IP_{10} SIZE SELECTIVE INLET

INTRODUCTION

Wind tunnel tests of candidate PM_{10} inlets represent part of the required evaluation of samplers for use in monitoring PM_{10} concentrations in the atmosphere. The present liquid particle study at a windspeed of 2 km/h represents one part of the wind tunnel evaluation. The field tested Wedding IP_{10} and the clean Wedding IP_{10} size selective inlets for the high-volume sampler were tested sequentially using liquid aerosol particles composed of oleic acid tagged with uranine. The clean Wedding IP_{10} inlet was the same inlet used in previous wind tunnel tests. The field-tested inlet had been used over a 32-day period in an EPA field study of candidate PM_{10} samplers (Phoenix III, May 1986). The mean total suspended particulate (TSP) and PM_{10} concentrations over the 32-day field study were 206 $\mu g/m^3$ and 85 $\mu g/m^3$, respectively. This report describes the test procedures, results, and conclusions as to the acceptability of these inlets regarding liquid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Liquid oleic acid particles tagged with uranine were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). Liquid particle diameters were verified microscopically using Nye-Bar treated glass slides and a flattening coefficient determined by Olan-Figueroa et al. (1982).

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40 ft^3/min. Isokinetic measurements were made with a 7.25-in x 7.25-in horizontally mounted inlet backed by a glass fiber filter and operated at the same

nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were liquid oleic acid of 3, 5, 7, 9, 10, and 13 μm nominal aerodynamic diameter. The test sequence consisted of first running the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of the field-tested Wedding IP_{10} inlet, the isokinetic inlet, and the clean Wedding IP_{10} inlet. The internal surfaces of the inlet were washed with 500 mL of 0.1 N NaOH following each isokinetic run, and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Fluoro-Colorimeter II.

RESULTS

The liquid particle sampling effectiveness values and a summary of run results appear in Tables 1 and 2 for the clean Wedding IP_{10} and the field-tested Wedding IP_{10} inlets respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the liquid particle sampling effectiveness curves for both the clean and field-tested inlets. A smooth curve has been drawn through the data points and extrapolated (shown by the dotted lines) at large (>13μ) particle sizes. From Figure 1 it is seen that the D_{50} cutpoint for the field-tested inlet is 6.95 μm and for the clean Wedding inlet it is 9.35 μm. The slope of the curves, estimated by the parameter $\sigma_g = (D_{16}/D_{84})^{1/2}$, is 1.68 for the field-tested inlet and 1.30 for the clean inlet. An integration of the two curves was performed against an assumed aerosol size distribution and compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D-3.) The results of this comparison are presented in Table 3 along with a comparison of the D_{50} cutpoint and σ_g.

CONCLUSIONS

Based on this study, both the clean and field-tested Wedding IP_{10} size selective inlets meet the specification for liquid particle sampling effectiveness. The clean Wedding IP_{10} also meets the specification for 50-percent cutpoint; however, the field-tested inlet fails to meet the cutpoint criterion.

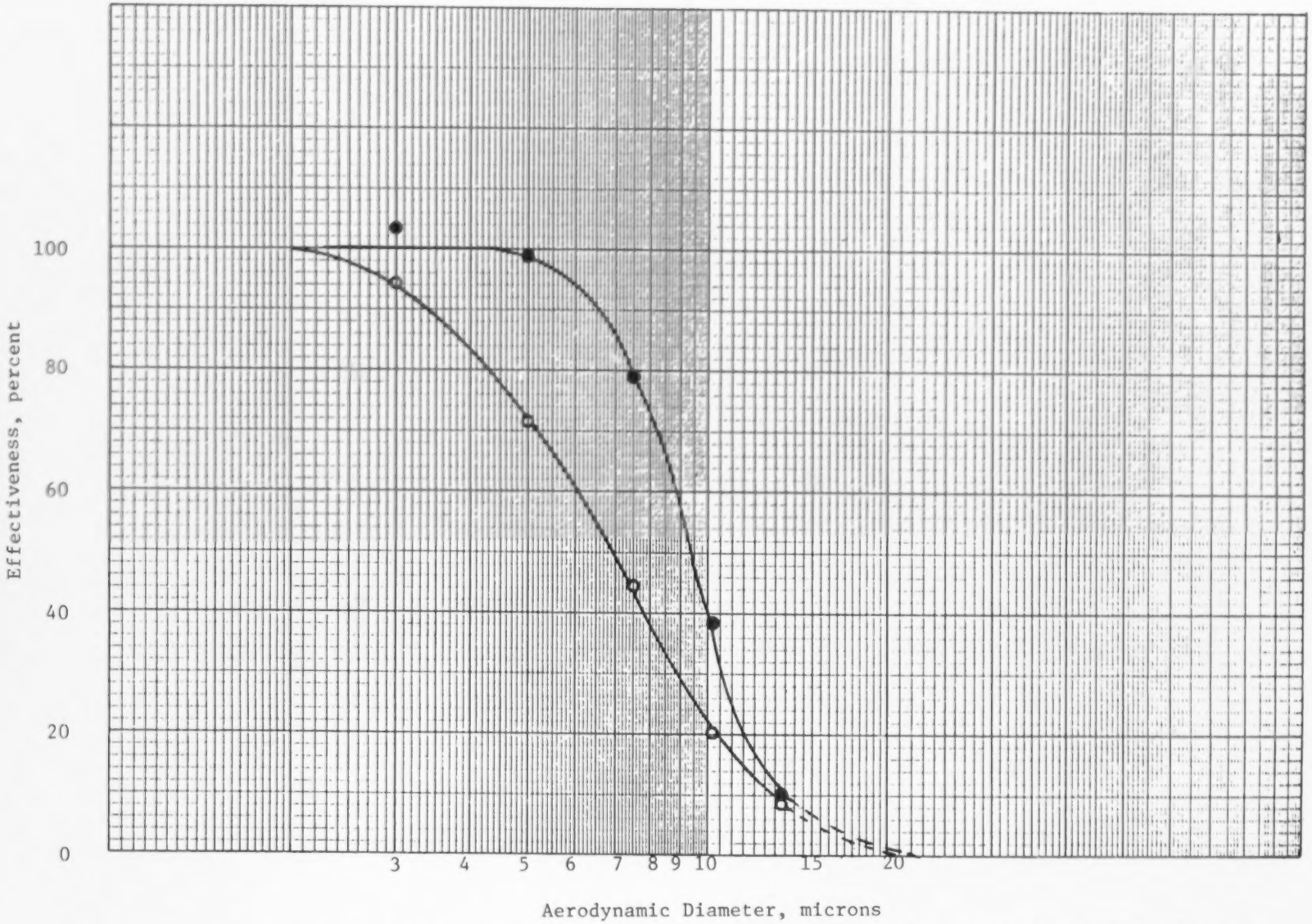


Figure 1. Liquid Particle Effectiveness Curves for the "Clean" (●) and "Dirty" Field Tested (O) Wedding IP_{10} Inlets at 2 Km/Hr.

TABLE 1. SUMMARY OF RESULTS FOR THE CLEAN WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.0	103.7	3.2	1.21	1.04	4.1
5.1	99.0	5.3	1.12	1.07	4.7
7.5	79.2	2.8	1.10	1.02	3.8
10.2	38.5	5.0	1.14	0.98	5.0
13.3	10.1	6.9	1.17	0.96	2.0

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 2. SUMMARY OF RESULTS FOR THE FIELD-TESTED WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
3.0	94.2	7.4	1.21	1.04	4.1
5.1	71.7	0.5	1.12	1.07	4.7
7.5	44.2	3.6	1.10	1.02	3.8
10.2	20.2	2.5	1.14	0.98	5.0
13.3	8.7	9.0	1.17	0.96	2.0

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 3. COMPARISON OF LIQUID PARTICLE RESULTS AT 2 km/h FOR THE CLEAN WEDDING IP_{10} AND FIELD-TESTED WEDDING IP_{10} INLETS

Parameter	Clean IP_{10}	Field-tested IP_{10}
Mass ratio[a]	0.989	0.936
50% cutpoint	9.35	6.95
σ_g	1.30	1.68

[a]This ratio is the mass collected by the test inlet (from integrating the effectiveness curve against an assumed aerosol size distribution) compared to the mass predicted for an "ideal" sampler using the aerosol size distribution in 49 FR 10461, Table D-3.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 19

LIQUID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} AND THE FIELD-TESTED WEDDING IP_{10}
SIZE SELECTIVE INLETS AT A WINDSPEED OF 2 km/h

TABLE A-1. SAMPLING EFFECTIVENESS VALUES FOR THE CLEAN WEDDING IP_{10} INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV (percent)
3.0	100.0, 104.5, 106.5	103.7	3.2
5.1	100.3, 103.5, 93.2	99.0	5.3
7.5	77.2, 78.9, 81.6	79.2	2.8
10.2	36.3, 39.8, 39.4	38.5	5.0
13.3	10.8, 9.4, 10.1	10.1	6.9

TABLE A-2. SAMPLING EFFECTIVENESS VALUES FOR THE FIELD TESTED WEDDING IP_{10} INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
3.0	102.0, 92.0, 88.6	94.2	7.4
5.1	71.9, 71.3, 72.0	71.7	0.5
7.5	45.8, 42.6, 44.1	44.2	3.6
10.2	20.1, 19.7, 20.7	20.2	2.5
13.3	9.2, 7.8, 9.1	8.7	9.0

4.7 EPA WIND TUNNEL TEST REPORT NO. 20: AN EVALUATION OF A "CLEAN" WEDDING IP_{10} AND A CLEANED, FIELD-TESTED WEDDING IP_{10} SIZE SELECTIVE INLET AT A WINDSPEED OF 2 km/h: LIQUID PARTICLES

ABSTRACT

Sequential liquid particle tests were performed at a windspeed of 2 km/h on a clean Wedding IP_{10} and a cleaned, field-tested Wedding IP_{10} size selective inlets at the EPA wind tunnel test facility. The cleaned field-tested inlet was designated inlet C in the EPA field study, and it will be referred to as inlet C in this interim report. Following the procedures outlined in 40 CFR Part 53 Subpart D, the tests were conducted with aerosol particles composed of oleic acid tagged with a uranine tracer covering the size range from 5 to 13 μm aerodynamic diameter. Based on results of these tests, both inlets meet the proposed specifications for liquid particle sampling effectiveness. The Wedding IP_{10} reference inlet also meets the cutpoint criterion, but inlet C does not meet the cutpoint criterion.

AN EVALUATION OF THE WEDDING IP_{10} AND -THE FIELD-TESTED INLET C SIZE SELECTIVE INLETS

INTRODUCTION

Wind tunnel tests of candidate PM-10 inlets represent part of the required evaluation of samplers for use in monitoring PM-10 concentrations in the atmosphere. The present liquid particle study at a windspeed of 2 km/h represents one part of the wind tunnel evaluation. The Wedding IP_{10} and the field-tested inlet C size selective inlets for the high-volume sampler were tested sequentially using liquid aerosol particles composed of oleic acid tagged with uranine. The Wedding IP_{10} inlet was the same inlet used in previous wind tunnel tests. Inlet C had been used over a 32-day period in an EPA field study of candidate PM_{10} samplers (Phoenix III, May 1986). After each sampling period, the top of the inlet was removed and the down tube of the inlet was subjected to simple brush cleaning. The mean total suspended particulate (TSP) and PM_{10} concentrations were 206 $\mu g/m^3$ and 85 $\mu m/^3$, respectively. This report contains descriptions of the test procedures, results, and conclusions as to the acceptability of these inlets regarding liquid particle sampling effectiveness. The conclusions contained herein represent the views of the authors and should not be construed to represent any formal acceptance by the U.S. Environmental Protection Agency (EPA).

TEST PROCEDURES

A characterization of the EPA wind tunnel test facility and the test procedures have been previously reported (Woods, Chen, Michaels, and Ranade, 1986). The wind tunnel is capable of sustaining uniform velocities from 2 to 24 km/h throughout the 4 ft x 5 ft test section. Liquid oleic acid particles tagged with uranine were generated as test aerosols using a vibrating orifice aerosol generator (Berglund and Liu, 1973). Liquid particle diameters were verified microscopically using Nye-Bar treated glass slides and a flattening coefficient determined by Olan-Figueroa et al. (1982).

Sampling effectiveness is the ratio of the concentration indicated by the test inlet to the actual concentration measured isokinetically. Sampler concentration measurements were made by connecting the inlet-filter holder combination to an externally mounted blower operated at a nominal flow rate of 40

ft^3/min. Isokinetic measurements were made by a 7.25-in x 7.25-in horizontally mounted inlet backed by a glass fiber filter and operated at the same nominal flow rate as the test inlets. Whatman EPM 2000 glass fiber filters (8 in x 10 in) were used. The effectiveness values reported here have not been corrected for multiplets.

Test aerosols were liquid oleic acid of 5, 7, 10, and 13 μm nominal aerodynamic diameter. The test sequence consisted of first running the isokinetic rake to verify the aerosol cloud uniformity followed by three replicates of inlet C, the isokinetic inlet, and the Wedding IP_{10} inlet. The internal surfaces of the isokinetic inlet were washed with 500 mL of 0.1 N NaOH following each isokinetic run and the concentration of the wash solution was included in the effectiveness calculations. The filters and wash solutions were analyzed fluorometrically using an SLM Aminco Flouro-Colorimeter II.

RESULTS

The liquid particle effectiveness values and a summary of run results appear in Tables 1 and 2 for the Wedding IP_{10} and inlet C, respectively. The individual effectiveness values for each particle size are compiled in Appendix A. Figure 1 contains the liquid particle sampling effectiveness curves for both the Wedding inlet and inlet C. A smooth curve has been drawn through the data points. From Figure 1 it is seen that the D_{50} cutpoint for inlet C is 8.7 μm and for the Wedding inlet it is 9.35 μm. The slope of the curves, estimated by the parameter $\sigma_g = (D_{16}/D_{84})^{1/2}$, is 1.28 for the Wedding inlet and 1.36 for inlet C. An integration of the two curves can be carried out against an assumed aerosol size distribution and compared to the expected mass predicted for an "ideal" sampler. (The aerosol size distribution is taken from 49 FR 10461, Table D-3.) The results of this comparison are presented in Table 3 along with the results of the "dirty" field-tested Wedding IP_{10} inlet obtained previously and presented in report #19.

CONCLUSIONS

Based on this study, both the "clean" Wedding IP_{10} inlet and inlet C meet the specification for liquid particle sampling effectiveness. The "clean" inlet also meets the cutpoint specification; however, inlet C does not meet the cutpoint specification.

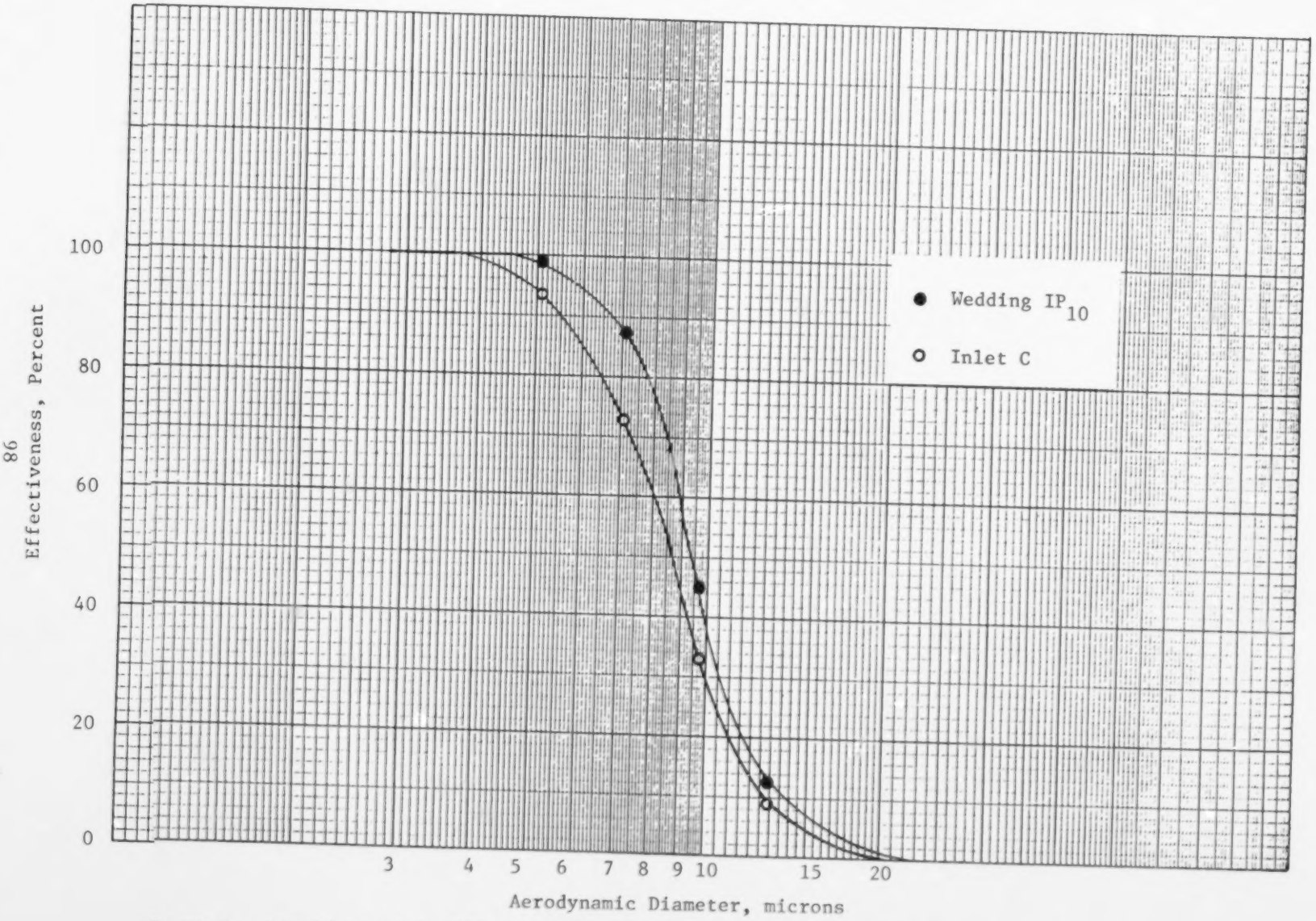


Figure 1. Liquid Particle Effectiveness Curves for the Wedding IP_{10} and Inlet C Obtained at a Wind Speed of 2 km/hr.

TABLE 1. SUMMARY OF RESULTS FOR THE WEDDING IP_{10} INLET

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
5.1	98.8	1.7	1.13	1.03	2.8
7.1	87.4	3.4	1.10	1.06	1.4
9.7	45.2	6.5	1.11	1.05	3.0
12.8	12.5	5.7	1.14	0.99	1.5

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 2. SUMMARY OF RESULTS FOR THE WEDDING INLET C

Particle size (μm)	Penetration (%)	CV (%)	Rake filter/ Iso filter[a]	Microscope size/ generator size[b]	Uniformity CV (%)[c]
5.1	93.4	1.3	1.13	1.03	2.8
7.1	73.0	1.4	1.10	1.06	1.4
9.7	33.1	1.4	1.11	1.05	3.0
12.8	8.9	2.6	1.14	0.99	1.5

[a]This ratio does NOT include nozzle wash readings.

[b]This ratio compares the microscopic particle size with the generator calculated size.

[c]The CV presented here does NOT include nozzle wash values.

TABLE 3. COMPARISON OF LIQUID PARTICLE RESULTS AT 2 km/h FOR THE WEDDING IP_{10}, THE "DIRTY" FIELD-TESTED IP_{10}, AND INLET C

Parameter	2 km/h		
	"Dirty" field-tested inlet	Inlet C	Clean IP_{10}
Mass ratio[a]	0.936	0.965	0.989
50% cutpoint	6.95	8.70	9.35
σ_g	1.68	1.36	1.28

[a]This ratio is the mass collected by the test inlet (from integrating the effectiveness curve against an assumed aerosol size distribution) compared to the mass collected by an "ideal" sampler using the aerosol size distribution in 49 FR 10461, Table D-3.

APPENDIX A

FOR EPA WIND TUNNEL TEST REPORT NO. 20

LIQUID PARTICLE SAMPLING EFFECTIVENESS VALUES
FOR THE WEDDING IP_{10} AND THE WEDDING INLET C
AT A WINDSPEED OF 2 km/h

TABLE A-1. EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET AT A WINDSPEED OF 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
5.1	100.4, 97.0, 98.9	98.8	1.7
7.1	84.2, 90.1, 87.8	87.4	3.4
9.7	42.2, 45.3, 48.1	45.2	6.5
12.8	11.7, 12.6, 13.1	12.5	5.7

TABLE A-2. EFFECTIVENESS VALUES FOR THE WEDDING IP_{10} INLET C AT 2 km/h

Particle size (μm)	Effectiveness values (percent)	Average (percent)	CV
5.1	94.8, 93.0, 92.5	93.4	1.3
7.1	71.8, 73.6, 73.6	73.0	1.4
9.7	32.8, 33.6, 32.8	33.1	1.4
12.8	9.0, 8.6, 9.0	8.9	2.6

APPENDIX A

DATA SHEETS FROM UNIFORMITY TESTS PERFORMED AT WINDSPEEDS OF 2, 8, AND 24 km/h

CONCENTRATION UNIFORMITY CHECK

DATE : 10/17/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 2.767315

AERODYNAMIC PARTICLE SIZE: 2.91 MICRONS

MICROSCOPIC SIZE CHECK : 2.9 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 78.2 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 2 km/hr
REL. HUMIDITY: 58 %
TEMPERATURE: 74 F
ATM. PRESSURE: 30.11 in. Hg

OLEIC/URANINE RATIO: 2.8482 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0287

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.252	0.095424	10.47139	1.045066
2	10.53 far top	0.224	0.084802	9.297318	0.927847
3	10.63 near mid	0.242	0.091630	9.951472	0.993130
4	10.46 middle	0.237	0.089733	9.903843	0.988376
5	10.58 far mid	0.24	0.090872	9.915705	0.989560
6	10.52 near low	0.265	0.100357	11.01322	1.099089
7	10.21 far low	0.224	0.084802	9.588713	0.956927

			C avg=	10.02030	
			Std dev=	0.524817	
			COV=	0.052375	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/22/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 10.08792

AERODYNAMIC PARTICLE SIZE: 10.10 MICRONS

MICROSCOPIC SIZE CHECK : 10.25 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 78.3 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 2 km/hr
REL. HUMIDITY: 52 %
TEMPERATURE: 72 F
ATM. PRESSURE: 29.84 in. Hg

OLEIC/URANINE RATIO: 5.18618 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0305

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m***3)	CONC/Cavg
1	10.52 near top	0.96	0.364498	64.30187	0.960126
2	10.53 far top	1.05	0.398741	70.27599	1.049329
3	10.63 near mid	0.97	0.368302	64.30069	0.960108
4	10.46 middle	1.01	0.383521	68.04590	1.016030
5	10.58 far mid	1	0.379716	66.60671	0.994541
6	10.52 near low	1.02	0.387326	68.32903	1.020258
7	10.21 far low	0.97	0.368302	66.94577	0.999604

			C avg=	66.97228	
			Std dev=	2.011068	
			COV=	0.030028	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/22/85
RUN # : 2

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 10.08792

AERODYNAMIC PARTICLE SIZE: 10.10 MICRONS

MICROSCOPIC SIZE CHECK : 10.25 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 78.3 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 2 km/hr
REL. HUMIDITY: 54 %
TEMPERATURE: 72 F
ATM. PRESSURE: 29.81 in. Hg

OLEIC/URANINE RATIO: 5.19618 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0305

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.924	0.350802	61.88582	0.971171
2	10.53 far top	0.936	0.355367	62.63161	0.982875
3	10.63 near mid	0.936	0.355367	62.04242	0.973628
4	10.46 middle	0.97	0.368302	65.34573	1.025467
5	10.58 far mid	0.927	0.351944	61.73505	0.968805
6	10.52 near low	1.03	0.391131	69.00027	1.082818
7	10.21 far low	0.919	0.348900	63.41908	0.995232

			C avg=	63.72285	
			Std dev=	2.447094	
			COV=	0.038402	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/17/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 2.767315

AERODYNAMIC PARTICLE SIZE: 2.91 MICRONS

MICROSCOPIC SIZE CHECK : 2.9 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 78.2 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 8 km/hr
REL. HUMIDITY: 58 %
TEMPERATURE: 74 F
ATM. PRESSURE: 30.15 in. Hg

OLEIC/URANINE RATIO: 2.8482 (Mass oleic acid / Mass uranine)

SAMPLE TIME 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0287

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.5 near top	0.0497	0.018758	2.062510	0.998260
2	10.78 far top	0.0511	0.019288	2.065643	0.999776
3	10.78 near mid	0.0536	0.020233	2.166909	1.048789
4	10.84 middle	0.0514	0.019401	2.066294	1.000091
5	10.87 far mid	0.0492	0.018569	1.972222	0.954560
6	10.92 near low	0.0527	0.019893	2.103139	1.017924
7	10.84 far low	0.0504	0.019023	2.026014	0.980596

			C avg=	2.066104	
			Std dev=	0.056019	
			COV=	0.027113	

CONCENTRATION UNIFORMITY CHECK

DATE : 11/11/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 5.28734

AERODYNAMIC PARTICLE SIZE: 5.40 MICRONS

MICROSCOPIC SIZE CHECK : 5.4 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 75.1 kHz
FEED RATE: 0.185 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 8 km/hr
REL. HUMIDITY: 56 %
TEMPERATURE: 72 F
ATM. PRESSURE: 30.01 in. Hg

OLEIC/URANINE RATIO: 2.08976 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 10 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0325

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.248	0.093907	8.274268	0.986571
2	10.53 far top	0.249	0.094286	8.299809	0.989617
3	10.63 near mid	0.25	0.094666	8.254815	0.984252
4	10.46 middle	0.257	0.097322	8.624344	1.028312
5	10.58 far mid	0.259	0.098081	8.593013	1.024576
6	10.52 near low	0.248	0.093907	8.274268	0.986571
7	10.21 far low	0.244	0.092389	8.387714	1.000098

			C avg=	8.386890	
			Std dev=	0.146026	
			COV=	0.017411	

CONCENTRATION UNIFORMITY CHECK

DATE : 11/1/95
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 10.17454

AERODYNAMIC PARTICLE SIZE: 10.20 MICRONS

MICROSCOPIC SIZE CHECK : 10.2 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 77.8 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 8 km/hr
REL. HUMIDITY: 62 %
TEMPERATURE: 70 F
ATM. PRESSURE: 29.28 in. Hg

OLEIC/URANINE RATIO: 5.18618 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0274

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.197	0.074561	13.15351	0.988139
2	10.53 far top	0.202	0.076457	13.47522	1.012307
3	10.63 near mid	0.204	0.077216	13.48089	1.012732
4	10.46 middle	0.192	0.072665	12.89254	0.968533
5	10.58 far mid	0.205	0.077595	13.61112	1.022516
6	10.52 near low	0.198	0.074940	13.22041	0.993165
7	10.21 far low	0.194	0.073423	13.34608	1.002605

			C avg=	13.31140	
			Std dev=	0.225279	
			COV=	0.016923	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/16/85
RUN # : 2

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 20.84361

AERODYNAMIC PARTICLE SIZE: 19.90 MICRONS

MICROSCOPIC SIZE CHECK : 21.1 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 77.6 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 8 km/hr
REL. HUMIDITY: 66 %
TEMPERATURE: 74 F
ATM. PRESSURE: 29.8 in. Hg

OLEIC/URANINE RATIO: 19.82031 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0293

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.139	0.052572	31.21417	0.968406
2	10.53 far top	0.145	0.054846	32.53337	1.009333
3	10.63 near mid	0.143	0.054088	31.79192	0.986020
4	10.46 middle	0.143	0.054088	32.29845	1.002045
5	10.58 far mid	0.141	0.053330	31.48463	0.976797
6	10.52 near low	0.15	0.056741	33.68949	1.045201
7	10.21 far low	0.141	0.053330	32.62560	1.012195
			C avg=	32.23252	
			Std dev=	0.771969	
			COV=	0.023950	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/17/85
RUN # : 2

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM
GENERATOR : 2.767315

AERODYNAMIC
PARTICLE SIZE: 2.91 MICRONS

MICROSCOPIC
SIZE CHECK : 2.9 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 78.2 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 24 km/hr
REL. HUMIDITY: 58 %
TEMPERATURE: 74 F
ATM. PRESSURE: 30.05 in. Hg

OLEIC/URANINE RATIO: 2.8482 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 120 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0287

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.087	0.032874	1.803804	0.929354
2	10.53 far top	0.095	0.035903	1.968147	1.014026
3	10.63 near mid	0.0877	0.033139	1.799530	0.927152
4	10.46 middle	0.0915	0.034578	1.908179	0.983130
5	10.58 far mid	0.094	0.035524	1.938185	0.998589
6	10.52 near low	0.099	0.037418	2.053135	1.057814
7	10.21 far low	0.099	0.037418	2.115473	1.089932

			C avg=	1.940922	
			Std dev=	0.109331	
			COV=	0.056329	

CONCENTRATION UNIFORMITY CHECK

DATE : 11/12/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 5.375545

AERODYNAMIC PARTICLE SIZE: 5.50 MICRONS

MICROSCOPIC SIZE CHECK : 5.5 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 72.5 kHz
FEED RATE: 0.185 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 24 km/hr
REL. HUMIDITY: 58 %
TEMPERATURE: 72 F
ATM. PRESSURE: 29.99 in. Hg

OLEIC/URANINE RATIO: 2.08976 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 60 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0377

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m***3)	CONC/Cavg
1	10.52 near top	0.0446	0.016830	1.482931	1.000400
2	10.53 far top	0.0456	0.017208	1.514808	1.021904
3	10.63 near mid	0.0445	0.016792	1.464289	0.987823
4	10.46 middle	0.046	0.017359	1.538349	1.037785
5	10.58 far mid	0.0456	0.017208	1.507650	1.017075
6	10.52 near low	0.043	0.016225	1.429628	0.964441
7	10.21 far low	0.042	0.015847	1.438710	0.970568
			C avg=	1.482338	
			Std dev=	0.037493	
			COV=	0.025293	

CONCENTRATION UNIFORMITY CHECK

DATE : 10/16/85
RUN # : 1

********** TEST PARAMETERS **********

TEST PARTICLE: LIQUID

SIZE FROM GENERATOR : 20.94361

AERODYNAMIC PARTICLE SIZE: 19.90 MICRONS

MICROSCOPIC SIZE CHECK : 21.1 MICRONS

******* GENERATOR PARAMETERS *******

FREQUENCY: 77.6 kHz
FEED RATE: 0.165 cc/min

**** WIND TUNNEL DATA ****

WIND SPEED: 24 km/hr
REL. HUMIDITY: 68 %
TEMPERATURE: 74 F
ATM. PRESSURE: 29.78 in. Hg

OLEIC/URANINE RATIO: 19.82031 (Mass oleic acid / Mass uranine)

SAMPLE TIME : 120 min

EXTRACTION VOLUME : 18 ml

********** TEST RESULTS **********

BLANK FILTER : 0.0293

NOZZLE #	FLOW LPM	FLUOROMETER READING	URAN CONC (ug/ml)	NON VOLATILE CONC(ug/m**3)	CONC/Cavg
1	10.52 near top	0.0884	0.033404	9.916669	1.008996
2	10.53 far top	0.0896	0.033858	10.04201	1.021749
3	10.63 near mid	0.0878	0.033177	9.747307	0.991764
4	10.46 middle	0.0862	0.032571	9.724851	0.989479
5	10.58 far mid	0.084	0.031738	9.368683	0.953240
6	10.52 near low	0.0842	0.031814	9.444595	0.960963
7	10.21 far low	0.0913	0.034502	10.55364	1.073806

			C avg=	9.823251	
			Std dev=	0.369428	
			COV=	0.037588	

APPENDIX B

METRIC CONVERSION TABLE

TABLE B-1. METRIC CONVERSION TABLE

To convert from	To	Multiply by
Cubic feet per minute (ft^3/min [also cfm])	Cubic meters per second (m^3/s)	$4.719\ 474 \times 10^{-4}$
Degree Fahrenheit (°F)	Degree Celsius (°C)	5/9 (after subtracting 32)
Feet per second (ft/s)	Meters per second (m/s)	$3.048\ 000 \times 10^{-1}$
Foot (ft)	Meter (m)	$3.048\ 000 \times 10^{-1}$
Horsepower (hp)	Watt (W)	$7.460\ 000 \times 10^{2}$
Inch (in)	Centimeter (cm)	2.54
Miles per hour (mi/h)	Kilometers per hour (km/h)[a]	1.609 344

[a]Although speedometers may read km/h, the System International (SI) unit is meters per second (m/s).